Draft

Report for Illinois River Watershed and Tenkiller Ferry Lake Nutrient TMDLs

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List of Acronyms and Abbreviations

Chl-a	Chlorophyll-a
COD	Chemical Oxygen Demand
COE	United States Army Corps of Engineers
ODEQ	Oklahoma Department of Environmental Quality
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
DON	Dissolved Organic Nitrogen
DOP	Dissolved Organic Phosphorus
DSLLC	Dynamic Solutions, LLC
EFDC	Environmental Fluid Dynamics Code
EPA	Environmental Protection Agency
HSPF	Hydrologic Simulation Program - Fortran
HUC	Hydrologic Unit Code
LPOC	Labile particulate organic carbon
LPON	Labile particulate organic nitrogen
LPOP	Labile particulate organic phosphorus
NLW	Nutrient Limited Waterbody
NPS	Nonpoint Source
OCC	Oklahoma Conservation Commission
OWRB	Oklahoma Water Resources Board
POM	Particulate Organic Matter
PON	Particulate Organic Nitrogen
POP	Particulate Organic Phosphorus
RMS	Root Mean Square
RMSE	Root Mean Square Error
RPOC	Refractory particulate organic carbon
RPON	Refractory particulate organic nitrogen
RPOP	Refractory particulate organic phosphorus
SOD	Sediment Oxygen Demand
TKN	Total Kjedhal Nitrogen (Total Organic Nitrogen + Ammonia-N)
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TOP	Total Organic Phosphorus
TP	Total Phosphorus
TPO4	Total Phosphate
TSI	Trophic State Index
TSS	Total Suspended Solids
USGS	United States Geological Survey

EXECUTIVE SUMMARY

Lake Thunderbird is a 6,070-acre reservoir located 13 miles east of downtown Norman in Cleveland County, Oklahoma. The Lake is located within a 256 square mile drainage area of the upper Little River watershed (HUC, 11090203). The Lake, owned by the U.S. Bureau of Reclamation, was constructed to provide flood control, municipal water supply, recreation and wildlife habitat. Lake Thunderbird is a prime recreational lake for camping, fishing, swimming and boating for the growing population in and around the watershed. As of the 2010 census, the watershed population is estimated at 99,600. The Lake serves as the primary public water supply for the cities of Norman, Midwest City, and Del City with water usage governed by the Central Oklahoma Master Conservancy District (COMCD). Lake Thunderbird is on Oklahoma's 2010 303(d) list for impaired beneficial uses of public/private water supply and warm water aquatic community (WWAC).

This report documents the data and assessment methods used to establish total maximum daily loads (TMDL) for Lake Thunderbird (OK520810000020_00). Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the federal Clean Water Act (CWA), Water Quality Planning and Management Regulations (40 CFR Part 130), United States Environmental Protection Agency (EPA) guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to the EPA for review and approval. Once the Environmental Protection Agency (EPA) approves a TMDL, the waterbody may then be moved to Category 4 of a state's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (EPA, 2003).

The purpose of this TMDL report is to establish waste load allocations (WLA) and load allocations (LA) determined to be necessary for reducing phosphorous and chlorophyll-a levels and maintaining sufficient oxygen levels in the Lake to attain water quality targets to restore impaired beneficial uses and protect public health. TMDLs determine the pollutant loading that a waterbody, such as Lake Thunderbird, can assimilate without exceeding applicable water quality standards. TMDLs also establish the pollutant load allocation necessary to meet the water quality standards established for a waterbody based on the relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of a waste load allocation (WLA), load allocation (LA), and a margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources, and includes stormwater discharges regulated under the National Pollutant Discharge Elimination System (NPDES) as point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint sources. The MOS is a percentage of the TMDL set aside to account for the lack of knowledge associated with natural processes in aquatic systems, model assumptions, and data limitations.

This report does not identify specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce pollutant loading from the watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watershed, along with local, state, and federal government agencies.

ES1. Problem Identification and Water Quality Targets

Designated uses of Tenkiller Ferry Lake are flood control, municipal water supply, recreation, and fish and wildlife propagation. Tenkiller Ferry Lake is designated as a Category 5a lake on the Oklahoma 303(d) list with a Priority 1 ranking. Category 5 defines a waterbody where, since the water quality standard is not attained, the waterbody is impaired or threatened for one or more designated uses by a pollutant(s), and the water body requires a TMDL. DEQ has determined that Tenkiller Ferry Lake, designated as a High Quality Water (HQW) lake, is not supporting its designated uses for (a) Fish & Wildlife Propagation (FWP) for a Warm Water Aquatic Community because of excessive levels of turbidity and low dissolved oxygen. High levels of both turbidity and chlorophyll-a can have deleterious effects on the raw water quality, such as taste and odor complaints and treatment costs of drinking water. Low levels of dissolved oxygen below the thermocline reflect decay of organic matter in the sediment bed and restricted transfer of oxygen from the surface layer because of summer thermal stratification. The water quality targets established for Tenkiller Ferry Lake, based on statistics of the most recent 10 years of record, are defined as the long-term average in-lake surface concentration of 10 µg/L for chlorophyll-a and the 90th percentile of the in-lake surface concentration of 25 NTU for turbidity. Water quality criteria for DO are defined for: (a) the surface layer (epilimnion) during periods of thermal stratification and (b) the entire water column when the lake is not stratified. A Warm Water Aquatic Community (WWAC) lake is fully supporting its designated beneficial uses for the epilimnion and the entire water column if 10% or less of DO samples are less than 6 mg/L from April 1 through June 15 and less than 5 mg/L during the remainder of the year (June 16 through March 31). DO criteria for a WWAC lake are also defined on the basis of the anoxic volume of the lake that is less than a target cutoff level of DO. During the period of thermal stratification, the lake is fully supporting if 50% or less of the lake volume is less than the target cutoff of 2 mg/L. The primary tributary to the reservoir, the Illinois River, is designated as a Scenic River and is protected and managed to assure its high-water quality.

ES2. Pollutant Source Assessment

Water quality constituents that relate to impairments of Tenkiller Ferry Lake include suspended sediment, chlorophyll-*a*, phosphorus, nitrogen, and carbonaceous biochemical oxygen demand (CBOD). The major contribution of pollutant sources from the watershed are derived from urban stormwater runoff from <??>. A smaller contribution of pollutant loading is related to runoff from rural and unincorporated areas of the watershed. A waste load allocation (WLA) for point source discharges of urban stormwater from ???, is determined for sediment, nutrients and CBOD. Urban stormwater discharges are regulated under the Clean Water Act by NPDES permits issued to the three cities as part of the MS4 Stormwater Program. A load allocation (LA) for nonpoint runoff of sediment, nutrients and ultimate CBOD is determined for the unincorporated area of the watershed not included within the boundaries of the three MS4 permits, along with the very small areas of the cities of Noble and Midwest City located in the watershed.

ES3. Watershed and Lake Model

A model framework was developed to establish the cause-effect linkage between pollutant loading from the watershed (the HSPF model) and water quality conditions in the lake (the EFDC model). Flow and pollutant loading from the watershed to the Lake was simulated for a one year period from April 2008 to April 2009 with the public domain HSPF watershed model. Watershed model results were used to estimate the relative contributions of point and nonpoint sources of pollutant loading. As shown in Table ES-1, the three cities of Moore, Norman and

Oklahoma City accounted for the dominant share of total pollutant loading from the watershed. The EFDC model was developed to simulate water quality conditions in Lake Thunderbird for sediments, nutrients, organic matter, dissolved oxygen and chlorophyll-*a*.

Table ES-1 Relative Contribution of Point and Nonpoint Source Loading of Pollutants from the Illinois River Watershed (Period ?)

Insert table here..

Model results for suspended solids were transformed to turbidity for comparison to water quality criteria for turbidity. Simulated suspended solids were transformed with a site-specific regression relationship developed from Lake Thunderbird station records for TSS and turbidity. EFDC is a public domain surface water model that includes hydrodynamics, sediment transport, water quality, eutrophication and sediment diagenesis. The EFDC lake model was developed with water quality data collected at eight locations in the Lake during the one year period from April 2008 through April 2009. Model results were calibrated to observations for water level, water temperature, TSS, nitrogen, phosphorus, dissolved oxygen, organic carbon and algae biomass (chlorophyll-a). The Relative RMS Error performance targets of (a) 20% for water level and dissolved oxygen; (b) 50% for water temperature, nitrate and total organic phosphorus; and (c) 100% for chlorophyll-a were all attained with the model results for these constituents either much better than, or close to, the target criteria. The model results for TSS, total phosphorus, total phosphate, and total nitrogen were also good with the model performance statistics shown to be only 5-6% over the target criteria of 50%.

The calibrated lake model was used to evaluate the water quality response to reductions in watershed loading of sediment and nutrients. Load reduction scenario model runs were performed to determine if water quality targets for turbidity and chlorophyll could be attained with watershed-based load reductions based on 35% removal of loading for sediment and nutrients. The long-term model results indicated that compliance with water quality criteria for turbidity, dissolved oxygen and chlorophyll could be achieved within a reasonable time frame. The calibrated model results thus supported the development of TMDLs for sediments, CBOD, TN and TP to achieve compliance with water quality standards for turbidity, chlorophyll and dissolved oxygen.

ES4. TMDL, Waste Load Allocation, Load Allocation and Margin of Safety

The linked watershed (HSPF) and lake (EFDC) model framework was used to calculate average annual suspended solids, CBOD, nitrogen and phosphorus loads (kg/yr) that, if achieved, should meet the water quality targets established for turbidity, chlorophyll-*a*, and dissolved oxygen. For reporting purposes, the final TMDLs, according to EPA guidelines, are expressed as daily loads (kg/day). The waste load allocation (WLA) for the TMDL for Lake Thunderbird is assigned to regulated NPDES point source discharges under three MS4 stormwater permits for Moore, Norman and Oklahoma City. The WLA, split among the three MS4 permits, includes pollutant discharges regulated under NPDES stormwater permits for Construction Sites and Multi-Sector General Permit (MSGP) for various industrial facilities located within the MS4 areas of the watershed. The load allocation (LA) for the TMDL is assigned to the small land area of the watershed not included in the land area for the three MS4 permits and is set at the existing loading during the calibration period.

Seasonal variation was accounted for in the TMDL determination for Lake Thunderbird in two ways: (1) water quality standards, and (2) the time period represented by the watershed and lake models. Oklahoma's water quality standards for dissolved oxygen for lakes are developed on a seasonal basis to be protective of fish and wildlife propagation for a warm water aquatic community at all life stages, including spawning. Within the surface layer, dissolved oxygen standards specify that DO levels shall be no less than 6 mg/L from April 1 to June 15 to be protective of early life stages and no less than 5 mg/L for the remainder of the year (June 16 to March 31). Under summer stratified conditions during the period from mid-May to October, the hypoxic volume of the lake, defined by a DO target of 2 mg/L, is not to be greater than 50% of the lake volume. Seasonality was also accounted for in the TMDL analysis by developing the models based on one full year of water quality data collected as part of a special study of Lake Thunderbird from April 2008-April 2009. The watershed and lake models were developed with hourly to sub-hourly time steps over a full year of simulation with meteorological data representative of typical average hydrologic conditions in the watershed. The TMDL determined for Lake Thunderbird accounts for an implicit Margin of Safety (MOS) by decreasing the water quality targets for chlorophyll-*a* and turbidity by a factor of 10%. The decrease resulted in the target for turbidity lowered from 25 to 22.5 NTU and the target for chlorophyll-*a* lowered from 10 to 9 µg/L.

The TMDL for Suspended Solids, TN and TP, determined from the lake model response to watershed load reductions, is based on the 35% reduction of the existing 2008 - 2009 watershed loads estimated with the HSPF model. Load reductions for these constituents are needed because the water quality criteria for turbidity and chlorophyll-a are not met under the existing loading conditions. For CBOD, however, the TMDL is based on the existing 2008 - 2009 ultimate CBOD loading from the HSPF watershed model since the water quality criterion for dissolved oxygen is met under existing loading conditions with reserved capacities. For example, the predicted volumetric anoxic volume for Lake Thunderbird is only about 30% (Figure 0-1) while the standards allows up to 50% anoxic volume. This reserved capacity will act as the implicit margin of safety. The total WLA for the three MS4 cities was computed from the Total Maximum Daily Load (TMDL) that was in turn derived from the long term average daily load (LTA) and the coefficient of variation (CV) estimated from HSPF loading data. The statistical methodology, documented in EPA (2007) "Options for Expressing Daily Loads in TMDLs", for computing the maximum daily load (MDL) limit is based on a long-term average load (LTA), temporal variability of the pollutant loading dataset expressed by the coefficient of variation (CV), the Z-score statistic (1.645) for 95% probability of occurrence and the assumption that streamflow and pollutant loading from the watershed can be described as a lognormal distribution (Table ES-2)

Table ES- 2 Existing Loading and TMDL for Illinois River Watershed and Tenkiller Ferry Lake

Add the Tabular info

The load allocation (LA) is computed as the difference from the total maximum daily load (TMDL) and the total WLA load. The TMDL load is split between three WLAs for the three MS4 cities, the LA for the unincorporated area of the watershed and the implicit MOS as shown in Table ES-3.

Table ES- 3 TMDL for Illinois River Watershed and Tenkiller Ferry Lake

Add the Tabular info

ES5. Public Participation

On <INSERT DATE> there was an informational meeting for the public to discuss the TMDL process for Illinois River Watershed and Tenkiller Ferry Lake. On <INSERT DATE>, EPA preliminarily approved the draft TMDL report and gave permission to go forward with the Public Comment period. The public comment period was open from <INSERT DATE> to <INSERT DATE>. A Public Meeting was held the evening of <INSERT DATE>. By the time the public comment period ended, DEQ had received <# of Comments> comments from <# of entities> entities. The comments and responses can be found in Appendix G.

SECTION 1. INTRODUCTION

1.1. Clean Water Act and TMDL Program

Section 303(d) of the federal Clean Water Act (CWA) and U.S. Environmental Protection Agency (EPA) Water Quality Planning and Management Regulations (40 Code of Federal Regulations [CFR] Part 130) require states to develop total maximum daily loads (TMDL) for waterbodies not meeting designated uses where technology-based controls are in place. TMDLs establish the allowable loadings of pollutants or other quantifiable parameters for a waterbody based on the relationship between pollution sources and in-stream water quality conditions, so States can implement water quality-based controls to reduce pollution from point and nonpoint sources and restore and maintain water quality (EPA, 1991a).

Several segments of the Illinois River have been and currently are on the State of Oklahoma's 303(d) list for Total Phosphorus (TP), while the mainstem Illinois River in Arkansas is not listed for TP. However, several tributaries to the Illinois River in Arkansas (e.g. Osage Creek, Muddy Fork, and Spring Creek) are designated as Phosphorus-impaired and included in the State's Clean Water Act 303(d) list.

Tenkiller Ferry Lake is identified on Oklahoma's 2010 303(d) list as impaired because of elevated nutrients, and it is a high-priority target for TMDL development (ODEQ, 2010). Tenkiller Ferry Lake is also listed as a Nutrient Limited Waters (NLW) indicating that the aesthetics beneficial use is considered threatened by nutrients (OWRB, 2013). Water quality impairments in the lake are for dissolved oxygen (DO), chlorophyll a, and trophic state index (TSI). Analysis of the water quality data collected by OWRB indicates that eutrophication of the lake occurs during summer periods, which is primarily attributed to excess phosphorus inputs from both point and nonpoint sources, especially from the untreated poultry litter on watershed pasture (Cooke et al., 2011).

The purpose of this TMDL report is to establish phosphorous load allocations for the Illinois River tributaries that is necessary for improving chlorophyll-a, dissolved oxygen and trophic state index (TSI) levels in the Tenkiller Ferry Lake as the first step toward restoring water quality and protecting public health in this waterbody. TMDLs determine the pollutant loading a waterbody can assimilate without exceeding applicable water quality standards (WQS). TMDLs also establish the pollutant load allocation necessary to meet the WQS established for a waterbody based on the cause-effect relationship between pollutant sources and water quality conditions in the waterbody. A TMDL consists of three components: (1) wasteload allocation (WLA), (2) load allocation (LA), and (3) margin of safety (MOS). The WLA is the fraction of the total pollutant load apportioned to point sources, and includes stormwater discharges regulated under the National Pollutant Discharge Elimination System (NPDES) as point sources. The LA is the fraction of the total pollutant load apportioned to nonpoint sources (NPS). The MOS is a percentage of the TMDL set aside to account for the lack of knowledge associated with natural process in aquatic systems, surface water model assumptions, and data limitations.

Data assessment and TMDL calculations are conducted in accordance with requirements of Section 303(d) of the CWA, Water Quality Planning and Management Regulations (40 CFR Part 130), EPA guidance, and Oklahoma Department of Environmental Quality (DEQ) guidance and procedures. DEQ is required to submit all TMDLs to EPA for review and approval. Once the EPA approves a TMDL, then the waterbody may be moved to Category 4a of a State's Integrated Water Quality Monitoring and Assessment Report, where it remains until compliance with water quality standards (WQS) is achieved (EPA 2003).

This report does not stipulate specific control actions (regulatory controls) or management measures (voluntary best management practices) necessary to reduce nutrients within the Lake watershed. Watershed-specific control actions and management measures will be identified, selected, and implemented under a separate process involving stakeholders who live and work in the watersheds, along with local, state, and federal government agencies.

1.2. Illinois River Watershed and Tenkiller Ferry Lake Description

The Illinois River begins in the Ozark Mountains in the northwest corner of Arkansas, and flows for 50 miles west into northeastern Oklahoma (See Figure 8-1). The Arkansas portion of the Illinois River Watershed is characterized by rapidly developing urban areas and intensive agricultural animal production. It includes Benton, Washington and Crawford Counties and according to the US Census Bureau, the population of Benton and Washington Counties increased by 45% between 1990 and 2000. This growth rate continued through 2010 with Benton County growing at 44% and Washington County at 29%. Arkansas ranked second in the nation in broiler production in 1998. Benton and Washington Counties ranked first and second respectively in the state. Other livestock production such as turkey, cattle and hogs are also all significant in this area. Upon entering Oklahoma, the river flows southwest and then south through the mountains of eastern Oklahoma for 65 miles, until it enters the Tenkiller Ferry Lake reservoir, also known as Lake Tenkiller. The upper section of the Illinois River in Oklahoma is a designated scenic river and home to many native species of bass with spring runs of white bass. The lower section, below Tenkiller dam flows for 10 miles to the Arkansas River, and is a designated year-round trout stream, stocked with rainbow and brown trout.

Tenkiller Ferry Lake is located in the Illinois River watershed (Hydrologic Unit Code 11110103), which crosses the Oklahoma-Arkansas boundary and covers 1,053,032 acres. The Illinois River flows west-southwest from Arkansas and into Oklahoma, where it drains into Tenkiller Ferry Lake before flowing into the Arkansas River. Tenkiller Ferry Lake is located in the southwestern portion of the basin with an area of 12,900 acres (OWRB, 2013). The main tributaries to the lake include the Illinois River, Baron Fork, Tahlequah Creek, Flint Creek, and Caney Creek. Figure 1 shows the location of the Illinois River watershed, the Tenkiller Ferry Lake drainage basin, Tenkiller Ferry Lake, and its main tributaries.

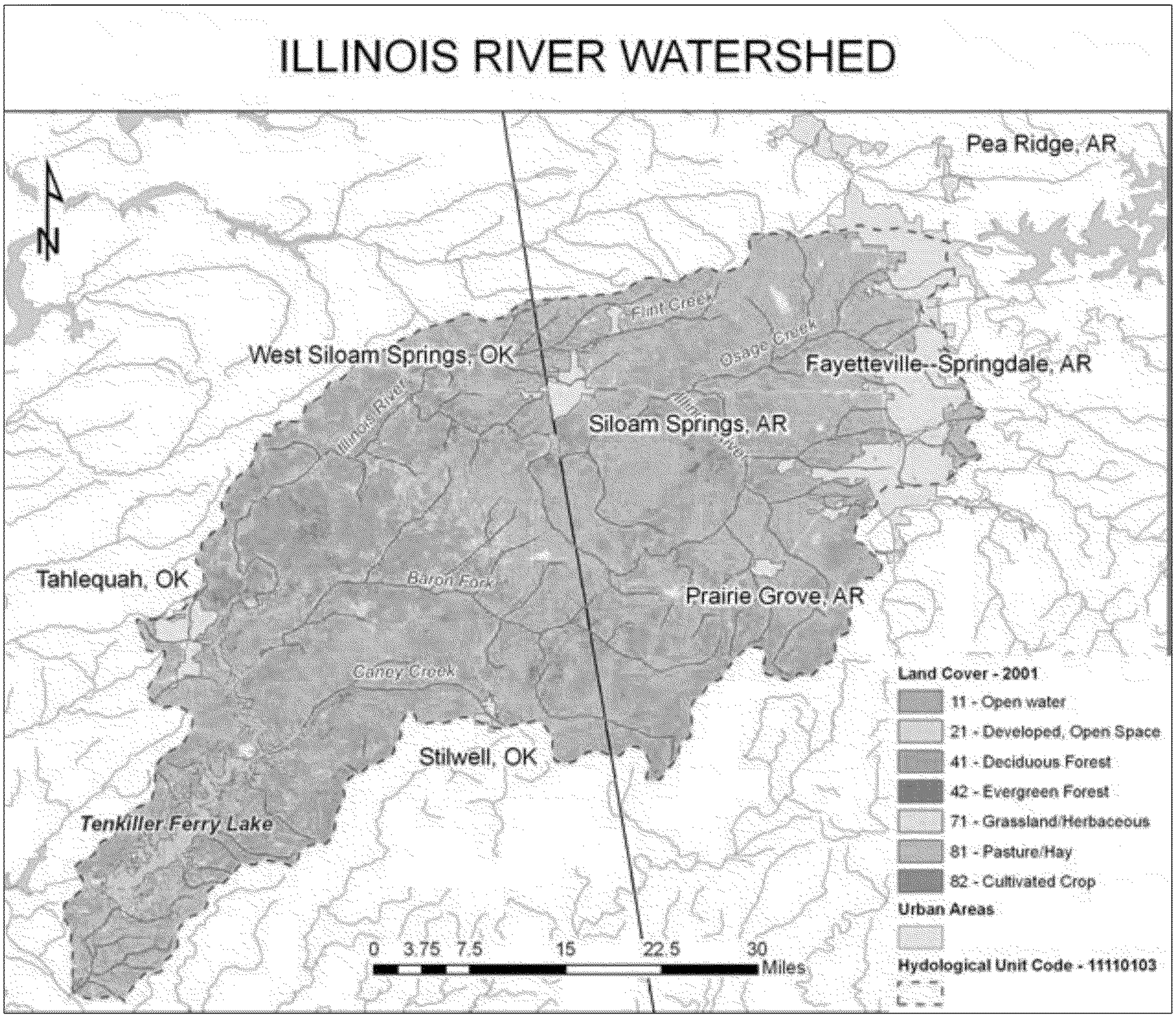


Figure 1-1. Location of Tenkiller Ferry Lake

SECTION 2. PROBLEM IDENTIFICATION AND WATER QUALITY TARGETS

2.1. Water Quality Standards/Criteria

Add a paragraph about WQS – especially AR and OK

2.1.1 Arkansas Water Quality Standards/Criteria

Water quality standards for Arkansas waterbodies are listed by ecoregion in Regulation No. 2 (Arkansas Pollution Control and Ecology Commission [APCEC] 2007a).

2.1.1.1 ***Arkansas Nutrient Criteria***

For nutrients, the Arkansas water quality standards have a narrative criterion but not a numeric criterion. The narrative criteria for nutrients in Arkansas are as follows:

Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation or otherwise impair any designated use of the waterbody. Impairment of a waterbody from excess nutrients is dependent 5-8 on the natural waterbody characteristics such as stream flow, residence time, stream slope, substrate type, canopy, riparian vegetation, primary use of waterbody, season of the year and ecoregion water chemistry. Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values, dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others. However, when excess nutrients result in an impairment, based upon Department assessment methodology, by any Arkansas established numeric water quality standard, the waterbody will be determined to be impaired by nutrients.

2.1.2 Oklahoma Water Quality Standards/Criteria

Chapters 45 and 46 of Title 785 of the Oklahoma Administrative Code (OAC) contain Oklahoma's WQS and implementation procedures, respectively. The Oklahoma Water Resources Board (OWRB) has statutory authority and responsibility concerning establishment of state water quality standards, as provided under 82 Oklahoma Statute [O.S.], §1085.30. This statute authorizes the OWRB to promulgate rules ...*which establish classifications of uses of waters of the state, criteria to maintain and protect such classifications, and other standards or policies pertaining to the quality of such waters*. [O.S. 82:1085:30(A)]. Beneficial uses are designated for all waters of the state. Such uses are protected through restrictions imposed by the anti-degradation policy statement, narrative water quality criteria, and numerical criteria (OWRB, 2011). An excerpt of the Oklahoma WQS (Chapter 45, Title 785) summarizing the State of Oklahoma Anti-degradation Policy is provided in Appendix C. Table 2-1, an excerpt from the 2010 Integrated Report (DEQ, 2010), lists beneficial uses designated for Tenkiller Ferry Lake. The beneficial uses include:

- AES – Aesthetics
- AG – Agriculture Water Supply

- FISH – Fish Consumption
- Fish and Wildlife Propagation
  - WWAC – Warm Water Aquatic Community
- PBCR – Primary Body Contact Recreation
- PPWS – Public & Private Water Supply
- HQW– High Quality Water
- SWS – Sensitive Public and Private Water Supply

Table 2-1 2010 Integrated Report – Oklahoma §303(d) List of Impaired Waters (Category 5a)

Waterbody ID	Waterbody Name	AES	AG	FISH	WWAC	PBCR	PPWS	HQW	SWS
Tenkiller Ferry Lake	OK121700020020_00	I	I	X	N	F	I	*	
Tenkiller Ferry Lake, Illinois River Arm	OK121700020220_00	N	I	X	N	F	N	*	
Illinois River	OK121700030010_00								
Illinois River	OK121700030080_00								
Illinois River	OK121700030280_00								
Illinois River	OK121700030350_00								

F – Fully supporting; N – Not supporting; I – Insufficient information; X – Not assessed
Source: 2010 Integrated Report, DEQ 2010

Table 2-2 summarizes the impairment status for Tenkiller Ferry Lake. Tenkiller Ferry Lake is designated as a Category 5a lake. Category 5 defines a waterbody where, since the water quality standard is not attained, the waterbody is impaired or threatened for one or more designated uses by a pollutant(s), and the water body requires a TMDL. This category constitutes the Section 303(d) list of waters impaired or threatened by a pollutant(s) for which one or more TMDL(s) are needed. Sub-Category 5a means that a TMDL is underway or will be scheduled. The TMDLs established in this report, which are a necessary step in the process of restoring water quality, address water quality issues related to nonattainment of the public and private water supply and warm water aquatic community beneficial uses.

Table 2-2 2010 Integrated Report – Oklahoma 303(d) List for Tenkiller Ferry Lake and Illinois River

Waterbody Name	Waterbody ID	Type	Size (acres for L and miles of R)	TMDL Date	Priority	DO	Chl-a	TP
OK121700020020_00	Tenkiller Ferry Lake	L	8,440	2012	1	X		
OK121700020220_00	Tenkiller Ferry Lake, Illinois River Arm	L	5,030	2012	1	X	X	
OK121700030010_00	Illinois River	R						X
OK121700030080_00	Illinois River	R						X

OK121700030280_00	Illinois River	R						X
OK121700030350_00	Illinois River	R						X

2.1.2.1 *Nutrient Standards for Scenic Rivers*

The following excerpt from the Oklahoma WQS [OAC 785:45-5-19(c)(2)] stipulates the nutrient numerical criterion for waters designated Scenic Rivers to maintain and protect "Aesthetics" beneficial uses (OWRB, 2011):

> *The thirty (30) day geometric mean total phosphorus concentration in waters designated "Scenic River" in Appendix A of this Chapter shall not exceed 0.037 mg/L. The criterion stated in this subparagraph applies in addition to, and shall be construed so as to be consistent with, any other provision of this Chapter which may be applicable to such waters. Such criterion became effective July 1, 2002 and shall be implemented as authorized by state law through Water Quality Standards Implementation Plans and other rules, permits, settlement agreements, consent orders, compliance orders, compliance schedules or voluntary measures designed to achieve full compliance with the criterion in the stream by June 30, 2012.*

2.1.2.2 *Dissolved Oxygen Standards for Lakes*

The following excerpt from the Oklahoma WQS [OAC 785:45-5-12(f)(1)(D)] stipulates the dissolved oxygen numeric criterion for lakes to maintain and protect "Warm Water Aquatic Community" beneficial uses (OWRB, 2011):

> *(v) Support tests for WWAC lakes. The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported with respect to the DO criterion if both the Surface and Water Column criteria prescribed in (vi)(I) and (vii)(I) of this subparagraph (D) are satisfied. If either of the Surface or Water Column criteria prescribed in (vi)(II) or (vii)(II) produce a result of undetermined, then the WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined with respect to the DO criterion; provided, if either of the Surface or Water Column criteria prescribed in (vi)(III) or (vii)(III) produce a result of not supported, then the WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported with respect to the DO criterion.*
>
> *(vi) Surface criteria for WWAC lakes.*
>
>> *(I) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported with respect to the DO criterion if 10% or less of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 6.0 mg/L from April 1 through June 15 and less than 5.0 mg/L during the remainder of the year.*
>>
>> *(II) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined with respect to the DO criterion if more than*
>>
>> *10% of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 5.0 mg/L and 10% or*

less of the samples are less than 4 mg/L from June 16 through October 15, or more than

10% of the samples from the surface are less than 6.0 mg/L and 10% or less of the samples are less than 5.0 mg/L from April 1 through June 15.

(III) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported with respect to the DO criterion if more than

10% of the samples from the epilimnion during periods of thermal stratification, or the entire water column when no stratification is present, are less than 5.0 mg/L from April 1 through June 15 or less than 4.0 mg/L from June 16 through October 15, or less than 5.0 mg/L from October 16 through March 31, due to other than naturally occurring conditions.

(vii) Water Column criteria for WWAC lakes.

(I) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be fully supported during periods of thermal stratification with respect to the DO criterion if less than 50% of the volume (if volumetric data is available) or 50% or less of the water column (if no volumetric data is available) of all sample sites in the lake are less than 2.0 mg/L.

(II) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be undetermined during periods of thermal stratification with respect to the DO criterion if 50% or more, but not greater than 70%, of the water column at any given sample site in the lake is less than 2.0 mg/L due to other than naturally occurring conditions.

(III) The WWAC subcategory of the Fish and Wildlife Propagation beneficial use designated for a lake shall be deemed to be not supported during periods of thermal stratification with respect to the DO criterion if 50% or more of the water volume (if volumetric data is available) or more than 70% of the water column (if no volumetric data is available) at any given sample site is less than 2.0 mg/L.

(IV) If a lake specific study including historical analysis produces a support status which is contrary to an assessment obtained from the application of (I), (II) or (III) of (D)(vii) of this section, then that lake specific result will control.

2.1.2.3 Chrolophyll-a Standards for SWS Lakes

Tenkiller Ferry Lake is designated as a Sensitive Public and Private Water Supply (SWS) lake. The definition of SWS is summarized by the following excerpt from OAC 785:45-5-25(c)(4) of the Oklahoma WQS (OWRB 2011):

(A) Waters designated "SWS" are those waters of the state which constitute sensitive public and private water supplies as a result of their unique physical conditions and are listed in Appendix of this Chapter as "SWS" waters. These are waters (a) currently used as water supply lakes, (b) that generally possess a watershed of less than approximately 100 square miles or (c) as otherwise designated by the Board.

> *(B) New point source discharges of any pollutant after June 11, 1989, and increased load of any specified pollutant from any point source discharge existing as of June 11,1989, shall be prohibited in any waterbody or watershed designated in Appendix A of this Chapter with the limitation "SWS". Any discharge of any pollutant to a waterbody designated "SWS" which would, if it occurred, lower existing water quality shall be prohibited, provided however that new point source discharge(s) or increased load of specified pollutants described in 785:45-5-25(b) may be approved by the permitting authority in those circumstances where the discharger demonstrates to the satisfaction of the permitting authority that a new point source discharge or increased load from an existing point source discharge will result in maintaining or improving the water quality of both the direct receiving water and any downstream waterbodies designated SWS.*

The following excerpt from the Oklahoma WQS (OAC 785:45-5-10) stipulates the numeric criterion set for Tenkiller Ferry Lake (OWRB, 2011).

> *785:45-5-10. Public and private water supplies*
>
> *The following criteria apply to surface waters of the state having the designated beneficial use of Public and Private Water Supplies:*
>
> *(7) Chlorophyll-a numerical criterion for certain waters. The long term average concentration of chlorophyll-a at a depth of 0.5 meters below the surface shall not exceed 0.010 milligrams per liter in Wister Lake, Tenkiller Ferry Reservoir, nor any waterbody designated SWS in Appendix A of this Chapter. Wherever such criterion is exceeded, numerical phosphorus or nitrogen criteria or both may be promulgated.*

In addition to the SWS designation of Tenkiller Ferry Lake, the Lake watershed has also been assigned the designation of “Nutrient Limited Watershed” (NLW) in OAC 785:45-5-29. A NLW means a watershed of a waterbody with a designated beneficial use that is adversely affected by excess nutrients as determined by Carlson's (1977) Trophic State Index (TSI) (using chlorophyll-*a*) of 62 or greater, or is otherwise listed as “NLW” in Appendix A of Chapter 45 (OWRB 2010).

2.2. Overview of Water Quality Problems and Issues

Describe WQ Issues

2.3. Water Quality Observations and Targets for Total Phosphorus, Dissolved Oxygen, and Chlorophyll a

Use the monitored numbers that we have. – Reaches 630, 830 Observations and Targets.

SECTION 3. POINT SOURCE ASSESSMENT

This section includes an assessment of the known and suspected sources of nutrients, organic matter and sediments contributing to the water quality impairments of Illinois River tributaries and Tenkiller Ferry Lake. Pollutant sources identified are categorized and quantified to the extent that reliable information is available. Generally, sediment and nutrient loadings causing impairment of lakes originate from point or nonpoint sources of pollution. Point source discharges are regulated under permits through the NPDES program. Nonpoint sources are diffuse sources that typically cannot be identified as entering a waterbody through a discrete conveyance, such as a pipe, at a single location. Nonpoint sources may originate from rainfall runoff and landscape dependent characteristics and processes that contribute sediment, organic matter and nutrient loads to surface waters. For the TMDLs presented in this report, all sources of pollutant loading not regulated under the NPDES permit system are considered nonpoint sources.

Under 40 CFR, §122.2, a point source is described as an identifiable, confined, and discrete conveyance from which pollutants are, or may be, discharged to surface waters. NPDES-permitted facilities classified as point sources that may contribute sediment, organic matter and nutrient loading include:

- NPDES municipal wastewater treatment plant (WWTP) discharges.
- NPDES industrial WWTP discharges.
- Municipal no-discharge WWTPs.
- NPDES municipal separate storm sewer system (MS4) discharges.
- NPDES Construction Site stormwater discharges.
- NPDES Multi-Sector General Permits (MSGP) stormwater discharges.
- NPDES concentrated animal feeding operations (CAFO)

Provide general description of available sources:

3.1. Assessment of Point Sources

3.1.1 NPDES Municipal and Industrial Wastewater Facilities

Data on point sources discharges have been compiled from a number of different sources of information, including data provided by EPA, State representatives, and the dischargers. Prior modeling efforts focused on the major dischargers, and ignored the contributions from the numerous minor and smaller ones. A similar approach is followed in this effort as the detailed time series data needed is not available for the minor dischargers.

Point source loads have been developed for 13 primary facilities (

Table **3.1**) that discharge to the Illinois River and its tributaries. The primary basis for developing the point source loads were (1) internal monitoring data provided by individual facilities (Springdale, Fayetteville, Lincoln, Rogers, Siloam Springs, Tahlequah, Stilwell) and (2) Discharge Monitoring Report (DMR) data provided by Oklahoma DEQ (Andrew Fang) and Arkansas DEQ. Bicknell and Donigian (2012) document the data, procedures, and assumptions that were used to develop the loads.

Table 3.1 Point Sources in Illinois River Watershed

NPDES #	Facility	Discharge Location	Typical
AR0022098	Prairie Grove, City of	Muddy Fork	0.3
AR0020010	Fayetteville - Paul Noland WWTP	Mud Ck	4.5
AR0050288	Fayetteville - Westside WWTP	Goose Ck	5.8
AR0033910	USDA FS - Lake Wedington Rec. Area	Tributary to Illinois R	0.0013
AR0035246	Lincoln, City of	Bush Ck/Baron Fork	0.45
AR0022063	Springdale WWTP, City of	Spring Ck/Osage Ck	12
AR0043397	Rogers, City of	Osage Ck	6.5
AR0020184	Gentry, City of	SWEPCO Res/L Flint Ck	0.45
AR0020273	Siloam Springs, City of	Sager Ck/Flint Ck	3
AR0037842	SWEPCO Flint Ck Power Plant	SWEPCO Res/Flint Ck	5/400 *
OK0026964	Tahlequah Public Works Authority	Tahlequah Ck	2.7
OK0028126	Westville Utility Authority	Shell Branch/Baron Fork	0.2
OK0030341	Stilwell Area Development Authority	Caney Ck	0.85
Add NACA			

* - Once-through cooling water outflow (400 MGD) and wastewater outflow (5 MGD)

3.1.2 NPDES Municipal Separate Storm Sewer System (MS4)

3.1.3 NPDES Construction Site Permits

3.1.4 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

3.1.5 NPDES Animal CAFOs

We may need to Currently there are no permitted CAFOs.

3.1.6 Missing Data

The general methodology for filling missing values was interpolation or averaging. Very little of the monthly data were missing. However, the daily/weekly data were filled in to generate daily time series by interpolation and averaging. Also, at the facilities where the monthly data did not extend over the entire period of point source data development (1990/1/1 - 2009/12/31), the existing data were extended back in time using selected averages of the existing data for that facility. For example, at the Lincoln facility, many of the constituents were not available prior to 2001, and were therefore estimated from the available data from 2001 through 2009. The procedures applied for filling in missing data at each facility are documented in Bicknell and Donigian (2012).

3.2. Assessment of Nonpoint Pollutant Sources

3.2.1 Atmospheric Deposition of Nutrients

Atmospheric deposition of nutrients is commonly included in watershed modeling efforts that focus on nutrient issues, like the current study. Atmospheric deposition data were obtained online through the National Atmospheric Deposition Program (NADP) (http://nadp.sws.uiuc.edu/) and the Clean Air Status and Trends Network (CASTNet) (http://java.epa.gov/castnet/). Sites in the NADP precipitation chemistry network began operations in 1978 with the goal of providing data on the amounts, trends, and geographic distributions of acids, nutrients, and base cations in precipitation. The network grew rapidly in the early 1980s funded by the National Acid Precipitation Assessment Program (NAPAP), established in 1981 to improve understanding of the causes and effects of acidic precipitation. Reflecting the federal NAPAP role in the NADP, the network name was changed to NADP National Trends Network (NTN). The NTN network currently has 250 sites.

CASTNet began collecting measurements in 1991 with the incorporation of 50 sites from the National Dry Deposition Network, which had been in operation since 1987. CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. CASTNET operates more than 80 regional sites throughout the contiguous United States, Alaska, and Canada. Sites are located in areas where urban influences are minimal. The primary sponsors of CASTNET are the Environmental Protection Agency and the National Park Service.

The data available from NADP/NTN are wet deposition of NH4 and NO3 in the form of precipitation-weighted concentrations (mg-N/L) on a monthly basis from 1980-2009. There are two active stations near the watershed: one is in Fayetteville, AR, and the other is in McClain County, OK. Two inactive stations in Oklahoma at Lake Eucha and Stilwell have data only for a limited period (2000-2003). There are no phosphorus data available.

The CASTNet data available for the watershed are weekly, quarterly, seasonal, and annual dry deposition fluxes of NH4, HNO3, and NO3- for 10/88-12/09. The stations near the watershed are Cherokee Nation in Adair County, OK and Caddo Valley in Clark County, AR. The Caddo Valley station is near an NADP station, but not the Fayetteville station.

There are very little data available to estimate phosphorus deposition. Most of the literature concludes that atmospheric deposition is a small contributor to the total P budget. Based on the available data and literature, we assume that atmospheric deposition of phosphorus is negligible compared to other sources.

3.2.2 Agricultural Land uses

3.2.3 On-site Sewage

3.2.4 Other Anthropogenic Sources

SECTION 4. MODELING APPROACH

In order to develop a scientifically sound modeling system to represent the entire IRW, including the land areas, the stream channels and Lake Tenkiller, models must be selected to represent each of these components. If the selected models are not already integrated within a single modeling system, the models must be linked to provide a comprehensive tool that addresses the watershed hydrology, generation of pollutants, fate/transport within the stream system, and ultimately dynamics and impacts on Tenkiller Ferry Lake.

As part of the study effort, a model selection task was performed and produced a Draft Model Selection Technical Memorandum dated November 22, 2010 (Donigian and Imhoff, 2010). This model comparison and selection process resulted in the recommendation that the US EPA HSPF (Hydrological Simulation Program – FORTRAN (Bicknell et al., 2005)) watershed model and the US EPA EFDC (Environmental Fluid Dynamics Code (Hamrick 1992, 1996; Tetra Tech, 2007) lake model be used in a linked application to provide the necessary modeling framework for performing this study. Following review and comments from project stakeholders, EPA subsequently agreed to the model recommendations and selected the HSPF watershed model and the EFDC lake model for this TMDL effort (M. Flores, personal communication, email to Project Stakeholders dated January 13, 2011).

HSPF was selected for the watershed because it provides a strong dynamic (i.e. short time step, hourly) hydrologic and hydraulic model simulation capability, and a moderately complex instream fate/transport simulation of sediment and phosphorus, both of which are linked to soil nutrient and runoff models; this combination provides a strong and established capability to relate upstream watershed point and nonpoint source contributions to downstream conditions and impacts at both the AR/OK state line and to Lake Tenkiller.

EFDC was selected because it allows a more mechanistic modeling of thermal stratification and is capable of a high level of spatial resolution in Lake Tenkiller, both of which are essential to support water quality compliance issues in OK, particularly time- and space-varying anoxic conditions. EFDC also provides moderately complex *biochemical* process representation that enables modeling and evaluation of chlorophyll *a* concentrations expressed as Carlson's Trophic State Index (TSI). Oklahoma statutes use TSI values to determine whether or not water bodies are threatened by nutrients. The EFDC water quality model is internally coupled to a sediment diagenesis model (Di Toro, 2001) so that the effect of external nutrient loading on organic matter production and settling to the bed, decomposition within the bed, sediment oxygen demand and benthic release of nutrients to the lake can be simulated within a consistent mass balance model framework. The sediment diagenesis model is the only lake model methodology available to provide a simulated cause-effect link between watershed loading, nutrient enrichment, eutrophication, sediment oxygen demand and internal release of nutrients from the lake bed back to the water column.

4.1. HSPF Watershed Model

4.1.1 HSPF Model Overview Description

HSPF is a continuous watershed simulation model that produces a time history of water quantity and quality at any point in a watershed. HSPF is an extension and reformulation of several previously developed models: the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), the Hydrologic Simulation Program (HSP) including HSP Quality (Hydrocomp, 1977), the Agricultural Runoff Management (ARM) model (Donigian and Davis, 1978), and the Nonpoint Source Runoff (NPS) model (Donigian and Crawford, 1977).

4.1.2 Segmentation, Characterization, and Setup of HSPF Model

4.1.2.1 ***Watershed Boundaries***

Whenever any watershed model is set up and applied to a watershed, the entire study area must undergo a process sometimes referred to as 'segmentation'. The purpose of watershed segmentation is to divide the study area into individual land and channel segments, or pieces, that are assumed to demonstrate relatively homogenous hydrologic/hydraulic and water quality behavior. This segmentation provides the basis for assigning similar or identical input and/or parameter values or functions to where they can be applied logically to all portions of a land area or channel length contained within a model segment. Since most watershed models differentiate between land and channel portions of a watershed, and each is modeled separately, each undergoes a segmentation process to produce separate land and channel segments that are linked together to represent the entire watershed area.

The results of the land segmentation process are a series of model segments, sometimes call hydrologic response units (HRUs) that demonstrate similar hydrologic and water quality behavior. Over the past few decades, geographic information systems (GIS), and associated software tools, have become critical tools for watershed segmentation. Combined with advances in computing power, they have allowed the development of automated capabilities to efficiently perform the data-overlay process. GIS data used in the segmentation process that affect the hydrologic and water quality response of a watershed are: topography and elevation, hydrography/drainage patterns, land use and land cover, soils information, and other various types of spatial data.

The primary sources for GIS data obtained for the IRW were those accessed through the use of the BASINS data download capability, from the SWAT 2009 modeling files provided by OK DEQ, and additional data provided by stakeholders in response to the Federal Register data request. Through the BASINS interface a wide range of GIS data layers were downloaded and displayed. BASINS accesses GIS data from a variety of sources such as The National Land Cover Data (NLCD), National Hydrography Dataset (NHD), and the USGS seamless data server (http://seamless.usgs.gov/). Other sources include the earlier HSPF modeling efforts, Geospatial One-Stop (http://gos2.geodata.gov/wps/portal/gos), and contacts with the OK DEQ and AR DEQ. Geospatial One-Stop is an e-government initiative sponsored by the Federal Office of Management and Budget (OMB) to make it easier, faster, and less expensive for all levels of government and the public to access geospatial information

Following subsections describe the major categories of GIS data used in model segmentation, and describe the model segmentation of the IRW.

4.1.2.2 ***Topography***

GIS layers of topography provide elevation and slope values for the project area, and are needed for characterizing the landscape and the land areas of the watershed. These elevation values are used to delineate subbasins, determine average elevations for each model subbasin, and/or to compute average slopes for model subbasins and land uses within a subbasin.

The National Elevation Dataset (NED) available through BASINS 4.0 with a resolution of 30-meter as Digital Elevation Model (DEM) grid with vertical units in centimeters was used for the topography. This was augmented by 10-meter resolution DEM, available from the USGS seamless site; was used in the lower slope areas for better spatial resolution, as needed. The topography information for IRW is shown in Figure 3.1.

4.1.2.3 ***Soils***

Soils data is used to characterize the infiltration and soil moisture capacity characteristics of the watershed soils, along with the erodibility parameters for soil erosion. SSURGO (Soil Survey Spatial and Tabular Data) soils data for the IRW were downloaded from the USDA/NRCS Data Gateway site (http://soildatamart.nrcs.usda.gov/). SSURGO depicts information about the kinds and distribution of soils on the landscape. This dataset is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. This dataset consists of georeferenced digital map data, computerized tabular attribute data, and associated metadata.

The properties of this dataset of interest in this watershed modeling study are: soil description, slope gradient, water table depth, flooding frequency, available water storage, hydrologic group, and hydric group. Spatial data on the SCS Hydrologic Soil Groups (HSG) were obtained and used to generate a map of the spatial distribution of these properties, shown in **Error! Reference source not found.**. The HSG B, C, and D distributions by subwatershed will be used as a basis for model parameterization related to infiltration and soil moisture capacity values in the model.

4.1.2.4 ***Land Use***

Land use, or land cover, data is a critical factor in modeling complex multi-land use watersheds as it provides the detailed characterization of the potentially primary source of pollutants entering the streams and rivers as nonpoint source contributions. In addition the land use distribution has a major determining impact on the hydrologic response of the watershed.

As discussed in the Data Report, a number of sources of land use data were investigated but, at that time, no single, consistent coverage, spanning both States, existed for the entire IRW other than the 2001 NLCD. Fortunately, in early 2011, the 2006 NLCD data was released and provided the consistent recent coverage needed covering both States, and applicable to a relatively recent time period with significant available water quality data. Table 3.1 lists the land use categories and distributions for the 1992, 2002, and 2006 NLCD, while Table 3.2 shows the correspondence between the NLCD categories and the model categories. Figure 3.3 shows and compares the spatial distribution of the NLCD categories for the 2001 and 2006 data layers.

Both Table 3.1 and Table 3.2 are color-coded to identify likely groupings of land uses with similar characteristics, with dark green showing forest categories, light brown for grasslands and shrub/scrub, pink for urban developed categories, etc. Comparing the category distributions for the three different time periods indicates the following:

1. There are some obvious inconsistencies between 1992 and the more recent 2001 and 2006 distributions, most likely due to differences in classifications within categories. For

example, there is a big increase in grassland/herbaceous from 1991 to 2001, and a comparable decrease in cultivate cropland. Although cropland likely did decrease, the amount of the decrease indicates a classification issue.

2. Forest distributions between 1992 and 2001 also show a big jump in deciduous and decreases in both evergreens and mixed categories. However, the differences between 2001 and 2006 are relatively small and in the expected directions.
3. Developed land shows a decrease in the high and medium intensity categories, and then a big jump in the developed open space category, most likely due to a classification change. The changes in developed categories between 2001 and 2006 are more consistency and in the expected direction.
4. Overall, the land use distributions for 2001 and 2006 shown in Table 3.1 appear to be consistent, with modest changes and in the expected direction.

Based on this review of the NLCD data, the coverages for 2001 and 2006 appeared to be the most consistent and reliable, representative land use data layers for use in modeling the IRW. The Data Report also noted the availability of the USDA-NASS Cropland Data Layer (CDL) as a potential source of recent land use data, and digital orthophotos available from the State of Oklahoma. In addition, since the Data Report was submitted, land use coverages for the Arkansas portion of the IRW were obtained from the University of Arkansas Center for Advanced Spatial Technologies (CAST) for a number of years from 2003 to 2009. All of these additional land use data layers were available for refinements or adjustments to the NLCD coverage, as needed, for use in the watershed modeling.

Table 3.2 lists the 15 NLCD land use categories and their percentages for both 2001 and 2006, along with the aggregation of these categories into the eight categories that are simulated by the watershed model; the Open Water category is listed in Table 3.2 but its area is included in the model as the surface area of streams and lakes. The practice of aggregating GIS land use categories for modeling is common in watershed modeling, depending on study objectives and details of the GIS layers. Small percentages of a land use category, such as evergreen and mixed forests in Table 3.2, are lumped with the dominant category, with similar land use/land cover characteristics for modeling, such as deciduous forests in Table 3.2. It is often difficult to distinguish and quantify model parameter values for such similar categories with only slightly different characteristics. In a similar manner, grasslands, shrub/scrub and barren are combined into one category, and the wetland categories are combined into another. Since projecting the impacts of future urbanization is a common use of watershed models, the developed categories are mostly left intact. One exception is combining the medium and high intensity classes since these are often small fractions of the total area, and the difference between them is arbitrary in many cases.

Need to add Baseline Scenario info – NLCD 2011

Also add the EIA info and maps/tables

4.1.2.5 ***Streamflow Data***

Flow data is needed for both calibration and validation of the watershed model to ensure it is reproducing the hydrologic behavior of the IRW, and providing proper boundary inflows into Lake Tenkiller, along with its transport of sediment and water quality constituents. The BASINS download capability provided the means to access all the USGS flow (and water quality) data for sites in the watershed. Figure 4.1 shows the locations of the USGS gaging sites within the watershed, and **Error! Reference source not found.** lists their names, USGS ID numbers, periods of record, tributary areas, and elevations for selected sites. In addition, the Arkansas Water Resources Center (B. Haggard, personal communication, 2011) provided supplemental data for Ballard Creek and Moore's Creek for model application.

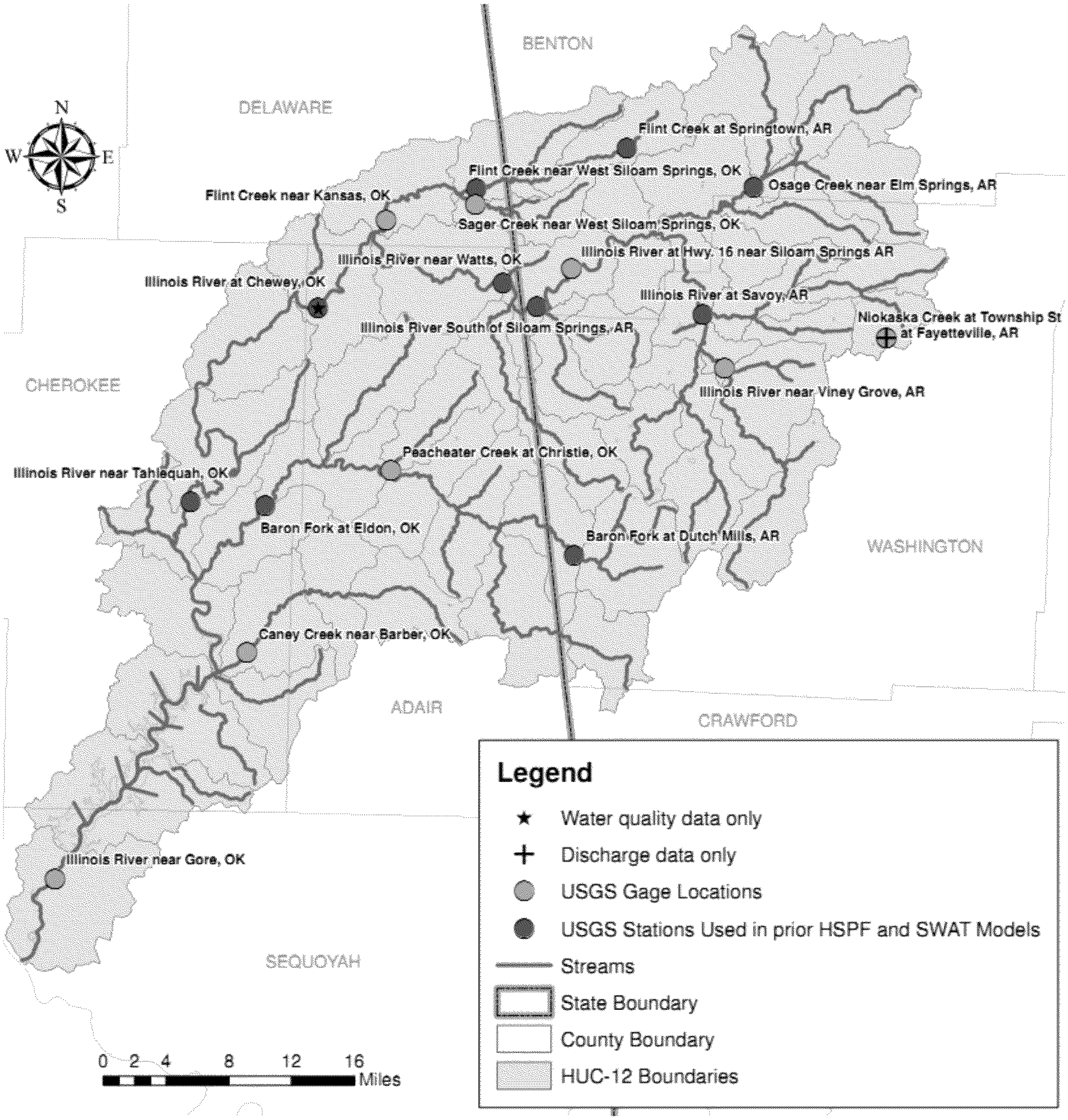


Figure 4.1 USGS Stream Gage Locations in the IRW

The USGS sites designated with red circles (●) are those used for model calibration and/or validation in the previous HSPF and SWAT model applications discussed above. However, no single model included ALL the gages shown in both states, until the current IRW modeling effort. Section 4 addresses the issue of selection of calibration/validation sites in both states, and the corresponding time periods. There are adequate periods of record for three to five calibration sites within each state, as discussed in Section 4.

Table x. USGS Stream Gages Containing Flow Data

Location	Gage Station	Period of Record		Tributary Area (mi²)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	10/1/1935	present	959.0	664
Baron Fork at Eldon, OK	07197000	10/1/1948	present	307.0	701
Baron Fork at Dutch Mills, AR	07196900	4/1/1958	present	40.6	986
Illinois River near Watts, OK	07195500	10/1/1955	present	635.0	894
Illinois River near Viney Grove, AR	07194760	9/5/1985	10/16/1986	80.7	1051
Illinois River at Savoy, AR	07194800	6/21/1979	present	167.0	1019
Niokaska Creek at Township St at Fayetteville, AR	07194809	9/19/1996	present	1.2	1482
Osage Creek near Elm Springs, AR	07195000	10/1/1950	present	130.0	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	6/21/1979	2/7/2011	509.0	1170
Illinois River South of Siloam Springs, AR	07195430	7/14/1995	present	575.0	909
Flint Creek at Springtown, AR	07195800	7/1/1961	present	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	10/1/1979	present	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	9/12/1996	present	18.9	960
Flint Creek near Kansas, OK	07196000	10/1/1955	present	110.0	855
Peacheater Creek at Christie, OK	07196973	9/1/1992	9/16/2004	25.0	802
Caney Creek near Barber, OK	07197360	10/1/1997	present	89.6	638
Illinois River near Gore, OK	07198000	3/25/1924	present	1626.0	468

4.1.2.6 ***Water Quality***

Water quality data is used primarily for model calibration and validation, but also to help quantify source contributions and boundary conditions, such as for point sources, selected agricultural sources, and atmospheric deposition. A number of agencies contributed a wide variety water quality related data to be used in this effort. The Draft Data Report (AQUA TERRA Consultants, 2010b) listed the specific sites and constituents available, along with the period of record for each site and constituent, to support the model application.

The specific constituents modeled in this study include all constituents needed for modeling nutrients, with a specific focus on phosphorus species. The following list shows the conventional constituents that are modeled whenever nutrients are the purpose of a modeling effort:

1. Flow/discharge
2. TSS
3. water temperature
4. DO
5. BOD ultimate, or total BOD
6. NO3/NO2, combined
7. NH3/NH4
8. Total N
9. PO4
10. Total P
11. Phytoplankton as Chl a

12. Benthic algae (as biomass)

These are the constituents that are modeled for the IRW; they include flow and TSS as the basic transport mechanisms for moving the nutrients, along with the environmental conditions (e.g. temperature) and other state variables (e.g. DO/BOD), that are involved in the aquatic fate, transport, and cycling of nutrients in aquatic systems.

For most modeling efforts of moderate to large watersheds, the USGS is the primary source of both flow and water quality data. In the IRW, the USGS works collaboratively with both the OK DEQ and AWRC for flow and water quality data collection efforts. Data was obtained from both the USGS NWIS system through direct downloading, along with files provided by the state agencies. **Error! Reference source not found.** lists the USGS flow gages that also include water quality data, along with their period of record. The Data Report provides a compilation of the number of data points and their period of record for each relevant water quality constituent, at each water quality observation gage.

As a supplement to the USGS water quality data, the AR Water Resources Center (AWRC) provided a series of annual reports, along with spreadsheets of loading calculations, for four sites within the AR portion of the IRW (B. Haggard, personal communication, 25 May 2010). Daily loads are available for the IR at Highway 59 (USGS gage #07195430), Ballard Creek, Moore's Creek, and Osage Creek, and for various time periods from 1999 to 2009 (see Nelson et al., 2006 as an example annual report).

Table 4.1 USGS Stream Gages with Water Quality Data in the IRW

Location	Gage Station #	Period of Record		Tributary Area (mi²)	Elevation (ft)
Illinois River near Tahlequah, OK	07196500	8/23/1955	12/15/2009	959	664
Baron Fork at Eldon, OK	07197000	5/7/1958	12/14/2009	307	701
Baron Fork at Dutch Mills, AR	07196900	3/17/1959	8/25/2009	40.6	986
Illinois River near Watts, OK	07195500	9/12/1955	10/26/2009	635	893
Illinois River near Viney Grove, AR	07194760	9/6/1978	7/19/2007	80.7	1051
Illinois River at Savoy, AR	07194800	9/11/1968	8/25/2009	167	1019
Osage Creek near Elm Springs, AR	07195000	9/10/1951	8/25/2009	130	1052
Illinois River at Hwy. 16 near Siloam Springs AR	07195400	9/8/1978	9/20/1994	509	1170
Illinois River South of Siloam Springs, AR	07195430	10/3/1972	8/25/2009	575	909
Flint Creek at Springtown, AR	07195800	10/15/1975	7/1/1996	14.2	1173
Flint Creek near West Siloam Springs, OK	07195855	7/11/1979	8/28/1996	59.8	954
Sager Creek near West Siloam Springs, OK	07195865	5/24/1991	10/21/2009	18.9	960
Flint Creek near Kansas, OK	07196000	9/7/1955	10/26/2009	110	855
Peacheater Creek at Christie, OK	07196973	8/6/1991	5/16/1995	25.0	802
Caney Creek near Barber, OK	07197360	8/25/1997	10/27/2009	89.6	638
Illinois River at Chewey, OK	07196090	7/16/1996	10/27/2009	825	801
Illinois River near Gore, OK	07198000	4/12/1940	8/16/1995	1626	468

4.1.2.7 ***Climate Data***

4.1.2.7.1 **Precipitation Data**

For hydrology calibration of the IRW, all watershed models require precipitation timeseries that are complete records (i.e., no missing data) at a daily or shorter timestep, depending on the selected model, and with adequate spatial coverage and density across the model domain. Precipitation is the critical forcing function for all watershed models as it drives the hydrologic cycle and provides the foundation for transport mechanisms, both flow and sediment, that move pollutants from the land to the waterbody where their impacts are imposed.

For this study, long-term precipitation data have been obtained from the following primary sources:

a. Prior modeling efforts with BASINS/HSPF and SWAT
b. Online databases (e.g., NOAA, USGS) accessed through the BASINS download data capability
c. OK Mesonet data network (provided by ODEQ)
d. Daily NEXRAD data (provided for AR by Drs Matlock and Saraswat at the University of Arkansas (Personal communication, 1 January 2011)
e. BASINS data extended through 12/31/09 (from an ongoing BASINS data project)

The last two precipitation data items (listed above) were obtained since the publication of the Draft Data Report in August 2010. Figure 2.1 shows the precipitation stations used in the IRW modeling effort. These stations are a subset of all the available stations, following a screening of the data to ensure recent and complete records from about 1980 through 2009. This time period provides a 30-year database to support longterm model runs for evaluation of watershed scenarios over a wide range of meteorologic conditions.

In addition to the actual precipitation gage stations, Figure 2.1 shows the ‘pseudo’ stations for the NEXRAD data (discussed below) for the AR portion of the watershed, and a Thiessen polygon analysis for the OK side of the watershed based on the locations of the NWS and OK Mesonet station locations. Thus, a hybrid approach is used, i.e. Thiessen analysis of gage stations on the OK side, and NEXRAD data on the AR side, to make use of the best available precipitation data on both sides of the watershed. Both of these approaches are further discussed below.

The Data Report identified an area of relatively sparse coverage on the AR side of the watershed, about the center of the area where the Illinois River bends toward the west (see Figure 2.1). The study was fortunate to obtain daily precipitation data from Drs Matlock and Saraswat at the University of Arkansas for 28 ‘pseudo’ gage sites (shown as the yellow circles in Figure 2.1), located at the approximate centroid of the HUC12 subwatersheds. This daily data set was developed as a combination of three NWS stations (Bentonville, Fayetteville, and Gravette) for the period 1981-93, and NWS NEXRAD (Next Generation Weather Radar) data for the period 1994-2008.

The station data for the early period (1981-93) were adjusted to the subwatershed centroids using an inverse distance weighting method developed by Zhang and Srinivasan (2009). The extension of these data through 2008 was derived from the NEXRAD Stage III data for 82 4x4 km grid cells within the IRW. In the words of Dr. Saraswat … “The data required several levels of post processing including unzipping, untarring, and transformation from the NEXRAD hydrological rainfall analysis project (HRAP) grid to a geographical coordinate system….. All NEXRAD grid points falling within a subwatershed were aggregated; an average value calculated; and assigned to pseudo weather stations at the centroid of the … subwatersheds." (Saraswat, 2010, pg. 18). These data help to fill in the sparse coverage on the AR portion of the IRW; however, due to the manner in which NWS observed data was processed and then combined with NEXRAD data to cover the 1981-2008 period for the 'pseudo' stations, further analysis and evaluation of these data sets was needed as part of the model setup and calibration efforts.

It is critical that the precipitation data demonstrate consistency across the entire IRW in order to produce a scientifically sound hydrologic model. Initial calibration runs demonstrated selected storms with extreme precipitation and little or no response at downstream flow gages, mostly in the AR portion of the watershed which received NEXRAD rainfall data. We referred to these as 'phantom' events since there was no evidence that such extreme rainfall events even occurred. Further analysis identified 10-15 events with rainfall totals at some of the NEXRAD 'pseudo' stations with extreme daily amounts in the range of 10 to 22 inches in a single day. Analysis of the NWS and OK Mesonet stations showed no single day rainfall greater than 8 inches for the entire record from1981 to 2009. Consequently, for these selected events we adjusted the rainfall for the outlier site based on rainfall amounts at neighboring sites. This does raise questions regarding the accuracy of the NEXRAD data for other non-extreme events.

On the OK side of the IRW, four Mesonet stations are combined with up to seven NWS stations, (denoted as BASINS in Figure 2.1, since they are available by download) to provide a reasonable coverage of the watershed within OK. An initial Thiessen analysis is shown in Figure 2.1 (green lines) for the OK side. A Thiessen analysis is a standard hydrologic technique to define the watershed area that will receive rainfall recorded at a specific gage; it involves constructing polygons around each gage using perpendicular bisecting lines drawn at the midpoint of connecting lines between each gage. In other words, the first step is to draw lines connecting the gages, then at the midpoint draw a perpendicular line, then erase the connecting lines; the result is a polygon around each gage. In Figure 2.1, there are nine gages for which the Thiessen analysis produced nine polygons;in the final model, this was reduced to seven polygons, as the Rose Tower gage was eliminated, and the Tahlequah and Webber Falls/Tenkiller polygons were combined into two polygons.

Table 2.1 tabulates all the available precipitation stations, and identifies the Mesonet sites and the specific stations used by Donigian et al (2009) in a prior HSPF/AQUATOX study. In addition to providing detailed 5-minute data, the Mesonet stations by their locations appear to fill in some areas with otherwise sparse gage coverage in the southern and western portions of the IRW. The Mesonet stations also provide extensive meteorologic data, discussed below.

Table 4.2 Precipitation Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Start	End	Av Annual Precip (in)
Bentonville 4S	AR030586	BASINS daily	12/31/1947	2/28/2007	46.79
Cookson	31	Mesonet 5-min	1/1/1994	5/26/2010	50.50
Fayetteville Exp Sta*	AR032444	BASINS hourly	4/1/1966	3/31/2006	46.17
Fayetteville Exp Sta*	AR032444	BASINS daily	12/14/1926	8/31/2003	46.17
Mountainburg 2NE	AR035018	BASINS daily	8/31/1985	12/31/2009	50.61
Natural Dam	AR035160	BASINS daily	12/31/1962	12/31/2009	49.39
Odell 2 N*	AR035354	BASINS daily	12/31/1947	12/31/2009	51.56
Kansas 2 NE*	OK344672	BASINS daily	3/31/1959	12/31/2009	48.23
Lyons 2 N*	OK345437	BASINS daily	12/31/1947	9/30/2003	47.75
Rose Tower*	OK347739	BASINS hourly	1/1/1974	12/31/2003	46.79
Stilwell 5 NNW*	OK348506	BASINS daily	9/30/1948	4/30/2003	49.11
Tahlequah*	OK348677	BASINS daily	12/31/1947	12/31/2006	47.64
Tahlequah	92	Mesonet 5-min	1/1/1994	5/26/2010	47.50
Tenkiller Ferry Dam*	OK348769	BASINS hourly	4/1/1949	1/31/1999	46.33
Webbers Falls	103, 132	Mesonet 5-min	1/1/1994	5/26/2010	46.50
Westville	104	Mesonet 5-min	1/1/1994	5/26/2010	48.90

*This station was previously used in the HSPF/AQUATOX study by Donigian et al (2009).

Based on the previous HSPF and SWAT modeling efforts, and the precipitation stations identified in Table 4.2 and **Error! Reference source not found.**, the coverage of daily stations appears sufficient for coverage of the IRW, especially with the addition of the Mesonet stations on the Oklahoma side and the NEXRAD data for the Arkansas side.

To simulate individual storm events, HSPF requires hourly data, and the conventional practice is to use nearby hourly stations to disaggregate daily precipitation values to hourly increments. The BASINS procedures for performing this disaggregation involve identifying up to 30 nearby stations, selecting the hourly station based on both geographic distance (proximity) and similarity of daily vales, and then using the hourly distribution at that station to transform the daily station value into 24 hourly values. A tolerance threshold is used to only select stations whose daily total is within a certain percentage of the daily value for the station being disaggregated. Typical tolerance values are in the range of 30% to 90%, depending on the availability of nearby alternate gages.

For the IRW, there are seven hourly stations, which include four Mesonet and three BASINS stations derived from NWS data. The combined Mesonet and BASINS hourly sites provide a good distribution for the OK side of the watershed, whereas hourly distributions for the AR side were derived from the Fayetteville, AR and from the Westville Mesonet site in OK.

Another indicator of rainfall patterns on the watershed is an annual isohyetal map, as shown in **Error! Reference source not found.**, which displays lines of equal annual rainfall (i.e., isohyets) across the watershed, based on the 1971-2000 period. The data for this map were obtained from the Oregon State University web site for their PRISM model (Parameter-elevation Regressions on Independent Slopes Model) (www.ocs.orst.edu/prism/). Gridded data, generated by this model based on point rainfall data, a DEM for topographic data, and other GIS data, was processed to produce the isohyets shown in the map. The information from **Error! Reference source not found.** can be helpful to assess the consistency of other rainfall estimates, and allow a determination of whether point rainfall data should be adjusted to better represent the area it is applied to. The pattern shows an overall range of 47 to 52 inches per year, but the large majority of the watershed experiences an annual range of only 48 to 50 inches.

4.1.2.7.1 **Evaporation and Other Meteoritical Data**

Watershed models require evaporation data as a companion to precipitation to drive the water balance calculations inherent in the hydrologic algorithms contained in these types of models. In addition, other meteorologic time series are also often required in temperate climates where snow accumulation and melt are a significant component of the hydrologic cycle and water balance. These same time series, such as air temperature, solar radiation, dewpoint temperature, wind, and cloud cover, are often required if soil and/or water temperatures are simulated. Water temperature is subsequently used to adjust rate coefficients in most water quality processes, and other time series are used in selected calculations, like solar radiation affecting algal growth.

Both HSPF and SWAT have similar weather data requirements (with some slight differences), so the availability of weather data is expected to be adequate for model application, considering both models have been previously applied to the IRW.

HSPF generally uses measured pan evaporation to derive an estimate of lake evaporation, which is considered equal to the potential evapotranspiration (PET) required by model algorithms, i.e., PET = (pan evap) X (pan coefficient). The actual simulated evapotranspiration is computed by the program based on the model algorithms that calculate dynamic soil moisture conditions, ET parameters, and the input PET data. Where pan evaporation is not available, potential evapotranspiration (PET) can be computed from minimum and maximum daily air temperatures using the Hamon formula (Hamon, 1961). This method was used to compute the PET data included in the BASINS database of available meteorologic time series. The Hamon method generates daily potential evapotranspiration (inches) using air temperature (F or C), a monthly variable coefficient, the number of daylight hours (computed from latitude), and absolute humidity (computed from air temperature).

Recently, BASINS has been enhanced to also allow computation of PET according to the Penman-Monteith method, which involves a more detailed computation requiring air temperature, solar radiation, relative humidity, and wind speed, along with other coefficients. The method incorporated into BASINS was based on procedures included in the SWAT model. As part of the model setup effort, PET estimates from both the Hamon and Penman-Monteith methods were compared, along with available pan evaporation data, and the Hamon method was selected as most representative of IRW. Initial calibration runs confirmed that the Hamon values were more consistent with the expected PET for the IRW.

The primary source of evapotranspiration and the other meteorologic data was the BASINS database of thousands of stations across the US; the download capability within BASINS allows users to identify their selected watersheds and then access all the data available, including meteorologic data. **Error! Reference source not found.** shows the available meteorologic stations in and near the IRW available through BASINS; it also shows the nearest OK Mesonet stations. The OK Mesonet is an automated network of hundreds of remote meteorologic stations across OK instrumented to monitor and measure soil and meteorologic conditions. As shown in **Error! Reference source not found.**, there are four Mesonet stations within or near the IRW.

Table 4.3 lists the meteorologic stations found through BASINS along with the Mesonet sites. The nearest pan evaporation station to the IRW is the Blue Mountain Dam NWS site approximately 30 miles southeast of the watershed. This site was used as the only evaporation data station for the HSPF/AQUATOX study; since PET generally demonstrates little spatial variability in this climate region, compared to rainfall variability, the distance was not considered excessive. Table 4.3 shows 14 sites with BASINS computed evapotranspiration data providing sufficient coverage for the IRW. Also, the stations available for the remaining weather data, combined with the Mesonet sites, appear to provide a similar level of coverage. As noted above, the various estimates of PET – Blue Mountain Dam pan data, Hamon method, Penman-Monteith method – were compared and the Hamon method was determined the most representative method to use for this study. In addition, Thiessen analyses, analogous to what was discussed above for the precipitation stations, were performed to identify the watershed areas for which each meteorological time series were applied. Since PET and air temperature are the more critical of the meteorologic forcing data sets, and more data sites are available, we have a denser network for PET and air temperature than for wind, solar radiation, dewpoint temperature, or cloud cover. The periods of available historic data for these meteorologic data, starting mostly about 1995, is consistent with our expected calibration and validation periods (discussed in Section 4).

Table 4.3 Meteorological Stations in/near the Illinois River Watershed

Site Name	Site Number	Source	Data Type	Start	End
Bentonville (AWOS)	AR723444	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Bentonville 4S	AR030586	BASINS	ATEM, PET	1/1/1948	2/28/2007
Blue Mountain Dam*1		Previous study	ATEM, PET	1/1/1984	9/30/2004
Cookson	31	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Fayetteville Exp Sta	AR032444	BASINS	ATEM, PET	8/26/1921	8/31/2003
Fayetteville FAA Airport	AR032443	BASINS	WIND, SOLR, DEWP, CLOUD	12/31/1994	12/31/2009
Kansas 2 NE	OK344672	BASINS	ATEM, PET	4/1/1959	1/1/2010
Muskogee	OK346130	BASINS	ATEM, PET	1/1/1948	12/31/2009
Rogers	AR723449	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Siloam Springs (AWOS)	AR723443	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1995	12/31/2009
Stilwell 5 NNW	OK348506	BASINS	ATEM, PET	1/1/1960	4/30/2003
Tahlequah	OK348677	BASINS	ATEM, PET	1/1/1948	12/31/2006
Tahlequah	92	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls	103, 132	Mesonet	ATEM, BP, SOLR, WIND	1/1/1994	present
Webbers Falls Dam	OK349450	BASINS	ATEM, PET, WIND, SOLR, DEWP, CLOUD	1/1/1970	12/31/2009

4.1.2.8 ***Pollutant Sources***

The data availability and frequency are summarized in **Error! Reference source not found.**, and the average daily values (in units of lbs/day) of all quantities for the full 1990-2009 period are shown in Table 4.4; spreadsheets of the daily and monthly values were provided to EPA and stakeholders November 2012. Total TN, TP, and $CBOD_u$ loads for 2009 are shown in Table 4.5. Although these tables show summaries of average daily and annual loads, the model actually receives the daily loads as a timeseries for the entire period of 1990-2009; these values are included with the daily load spreadsheet provided to EPA and stakeholders.

Table 4.4 Average Daily Point Source Loads for 1990-2009

Facility	Flow mgd	Heat btu/day	DO lb/day	TSS lb/day	$CBOD_5$ lb/day	$CBOD_U$ lb/day	Ref Org C lb/day	TP lb/day	PO4 lb/day	Org P lb/day	TN lb/day	NH3 lb/day	NO3 lb/day	OrgN lb/day
Prairie Grove	0.27	7.5E+7	19	19	9.0	25.5	2.4	10	7.7	2.6	17.4	1.9	11	4.4
Fayetteville Noland	3.9	1.1E+9	311	82	65	184	17	14	10	3.5	242	12	164	65
Fayetteville Westside (2008/6-2009)	5.8	1.7E+9	441	43	93	265	71	21	16	5.3	349	7.6	244	98
USDA-Lake Wedington	.0013	3.7E+5	0.095	0.063	0.050	0.14	0.014	.0046	.0035	.0012	.0864	0.011	0.054	0.022
Lincoln	0.46	1.1E+8	34	15	24	68	6.4	6.0	4.5	1.5	24.3	3.2	13	7.7
Springdale	11	3.2E+9	872	352	199	566	53	304	270	54	558	41	369	149
Rogers	5.5	1.5E+9	450	218	123	348	33	67	17	50	262	10	202	54
Gentry	0.47	1.3E+8	35	44	41	118	11	15	11	3.7	32	4	20	7.9
Siloam Springs	2.7	8.1E+8	187	203	73	207	19	76	57	19	290	13	231	46
SWEPCO	359	5.7E+11	2.7E+4	575	33*	94*	8.8*	15*	11*	3.7*	32*	4*	20*	7.9*
Tahlequah	2.7	7.7E+8	176	53	85	241	23	21	16	5.3	176	20	111	45
Westville	0.18	4.9E+7	13	38	18	50	4.7	3.1	2.3	0.8	13.2	2.8	7.5	3.0
Stilwell	0.71	2.0E+8	44	50	58	164	15	6.0	4.5	1.5	52.5	11.3	29	12

* SWEPCO nutrient loads based on Gentry data

Table 4.5 Annual Loads (lbs/year) of TP, TN, and $CBOD_u$ for 2009

NPDES #	Facility	TP	TN	$CBOD_u$
AR0022098	Prairie Grove	3,400	7,100	5,310
AR0020010	Fayetteville - Noland (2007)	3,980	125,000	126,000
AR0050288	Fayetteville - Westside	7,910	139,000	106,000
AR0033910	USDA FS - Lake Wedington	4.54	92.5	192
AR0035246	Lincoln	1,540	11,500	6,020
AR0022063	Springdale	16,900	248,000	169,000
AR0043397	Rogers	5,380	192,000	75,400
AR0020184	Gentry	4,920	13,600	19,000
AR0020273	Siloam Springs	12,600	63,000	42,000
AR0037842	SWEPCO	*4,920	*13,600	*19,000
OK0026964	Tahlequah	3,910	75,000	55,400
OK0028126	Westville	489	6,910	7,910
OK0030341	Stilwell	1,920	26,100	57,500

* SWEPCO loads based on Gentry data

The primary data available for many of the facilities was derived from DMR sources, and consists of monthly averages of flow and the following constituents: $CBOD_5$, TSS, DO, NH3, and TP. Eight of the facilities provided daily/weekly data for selected time periods, and those data were used when available. While it is likely that most flow rates are based on frequent (daily) measurements, the other constituent monthly averages were apparently obtained from one to two measurements per month. For five of the facilities, this type of monthly data are the only data available (facilities with "n/a" in **Error! Reference source not found.**); four of the facilities (Fayetteville-Noland, Fayetteville-Westside, Rogers, and Springdale) have essentially a complete period (1990/1/1 - 2009/12/31) of daily/weekly data; and the remaining four facilities (Lincoln, Siloam Springs, Tahlequah, and Stilwell) utilize monthly data for the earlier years, and are supplemented by more frequent measurements (typically weekly) for the later years. In general, where monthly and weekly (or daily) data overlapped in time, the more frequent measurements were used to develop the final loads.

4.1.3 HSPF Model Calibration

4.1.3.1 ***Hydrology Calibration and Validation***

4.1.3.2 ***Watershed Quality Calibration***

4.1.4 Pollutant Loads for Existing Condition

4.2. EFDC Lake Model

4.2.1 EFDC Model Description

The Environmental Fluid Dynamics Code (EFDC) is a general-purpose surface water modeling package for simulating three-dimensional (3-D) circulation, mass transport, sediments and biogeochemical processes in surface waters including rivers, lakes, estuaries, reservoirs, nearshore and continental shelf-scale coastal systems. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications (Hamrick, 1992; 1996). Over the past decade, the US Environmental Protection Agency (EPA) has continued to support its development, and EFDC is now part of a family of public domain surface water models recommended by EPA to support water quality investigations including TMDL studies. In addition to state of the art hydrodynamics with salinity, water temperature and dye tracer simulation capabilities, EFDC can also simulate cohesive and non-cohesive sediment transport, the transport and fate of toxic contaminants in the water and sediment bed, and water quality interactions that include dissolved oxygen, nutrients, organic carbon, algae and bacteria. A state of the art sediment diagenesis model (Di Toro, 2001) is internally coupled with the water quality model (Park et al., 2000). Special enhancements to the hydrodynamic code, such as vegetation resistance, drying and wetting, hydraulic structure representation, wave-current boundary layer interaction, and wave-induced currents, allow refined modeling of tidal systems, wetland and marsh systems, controlled-flow systems, and near-shore wave-induced currents and sediment transport. The EFDC code has been extensively tested, documented and used in more than 100 surface water modeling studies (Ji, 2008). The EFDC model is currently used by university, government, engineering and environmental consulting organizations worldwide.

Dynamic Solutions, LLC (DSLLC), has developed a version of the EFDC code that streamlines the modeling process and provides links to DSLLC's pre- and post-processing software tool EFDC_Explorer7 (Craig, 2013). The DSLLC version of the EFDC code is open source and DSLLC coordinates with EPA to provide ongoing updates and enhancements to both DSLLC's version of EFDC as well as the version of the EFDC code provided by EPA.

4.2.2 Data Sources and EFDC Model Setup

4.2.3 EFDC Model Calibration to Existing Conditions

4.2.4 Pollutant Loads for Existing Model Calibration

4.2.5 Water Quality Response to Modeled Load Reduction Scenarios

4.2.6 Pollutant Loads for Removal Scenario

4.2.7 Summary

SECTION 5. TMDL ALLOCATIONS

The purpose of the Loading allocation is to develop the framework for reducing pollutant loading under the existing watershed conditions so that water quality standards can be met. The Loading Allocations (L represents the maximum amount of pollutant that the stream can receive without exceeding the water quality criteria. The load allocations for the selected scenarios were calculated using the following equation:

$$\text{Loading Allocation} = \Sigma \text{ WLA} + \Sigma \text{ LA} + \text{MOS}$$

Where,

WLA = waste load allocation (point source contributions);
LA = load allocation (non-point source contributions); and
MOS = margin of safety.

Typically, several potential allocation strategies would achieve the Loading Allocation endpoint and water quality standards. Available control options depend on the number, location, and characteristics of the pollutant sources.

For the IRW, the Loading Allocation that would meet the Scenic River instream criteria for TP was determined through a series of model executions for alternative scenarios to ultimately arrive at the recommended Final TMDL scenario that would meet the TP criteria, of 0.037 mg/l TP, as a 30-day geomean of daily concentrations. These analyses were performed at both the AR/OK stateline (defined as the USGS gage 07195430 South of Siloam Springs and represented by Reach 630 in the Watershed Model), and the final Illinois River reach (Reach 890) draining to, and providing loadings to Tenkiller Ferry Lake.

In order to prepare for, and set the foundation for, the scenario analyses, the calibrated watershed model must first be revised to represent our best assessment of 'current' or Baseline conditions. This provides the 'starting point' to which the alternative scenarios are compared. As noted above, the IRW model was calibrated to data for the period of 2001 to 2009, using land use conditions, actual effluent discharges for the permitted point sources, litter application rates, fertilizer applications rates, atmospheric deposition, etc., all appropriate for that specific time period. Thus the results of the calibration runs are specific to the time period of the calibration, 2001 – 2009. For the Baseline run, we imposed a number of differences to approximate 'current' conditions on the watershed, for the general time period of about 2009-2015 to which alternative scenarios could be compared.

The specific differences between the calibration condition and the Baseline condition are as follows:

- The Baseline model time span is 1992-2009, 18 years; whereas the calibration span was 2001-2009.
- The Baseline run point sources are monthly values from 2015 (distributed to daily inputs) that are applied to each year of the run; we processed data that EPA Region 6 provided for the simulation.
- The Baseline land use is NLCD 2011 as opposed to the NLCD 2006 used in the calibration.

- Both runs have the baseflow added to RCHs 150, 304, 308 to account for low flow contributions from regional aquifers.
- Expert System/hydrology output (COPYs) has been removed from the Baseline run (does not impact the simulation results, just the time of execution).
- Litter application rates in the Baseline run are set to 2009 values for all years.
- Both runs have the updated monthly distribution for litter applications, and the updated 10% surface and 90% upper layer for litter applications.
- Both runs have updated RCHRES denitrification rates developed by EPA Region 6.
- Both runs have same manure application rates, and the same N fertilizer added to non-litter pasture.
- Both runs have same parameter values throughout.

5.1. Waste load allocation (WLA)

5.1.1 NPDES Municipal and Industrial Wastewater Facilities

5.1.2 NPDES Municipal Separate Storm Sewer System (MS4)

5.1.3 NPDES Construction Site Permits

5.1.4 NPDES Multi-Sector General Permits (MSGP) for Industrial Sites

5.1.5 NPDES Animal CAFOs

To represent the WLA loads in the IRW model, the point sources listed in Table 5.1 and included in the calibration were also included for the Baseline run using data from 2015 to generate the input loads, based on data provided by EPA Region 6. The only differences being the inclusion of the NACA facility, which came online in late 2009, and the closing of the Fayetteville-Nolan plant in 2007. Figure 5.1 shows the locations of the facilities listed in Table 5.1

Table 5.1 Annual Loads (lbs/yr) of TP, TN, and CBOD for 2015 used for Baseline Run and Scenarios

NPDES #	Facility	TP	TN	$CBOD_u$
AR0022098	Prairie Grove	783	10,999	8,772
AR0020010	Fayetteville - Noland (2007)	-	-	-
AR0050288	Fayetteville - Westside	3,210	178,768	35,865
AR0033910	USDA FS - Lake Wedington	3	138	67
AR0035246	Lincoln	439	12,609	5,528
AR0022063	Springdale	10,479	309,583	54,693
AR0043397	Rogers	4,525	199,983	28,688

AR0020184	Gentry	4,176	12,903	14,614
AR0020273	Siloam Springs	2,418	35,314	48,819
AR0037842	SWEPCO	-	-	-
OK0026964	Tahlequah	2,518	83,822	27,104
OK0028126	Westville	283	3,703	1,664
OK0030341	Stilwell	3,124	32,261	26,794
AR0050024	NACA	378	61,203	14,140

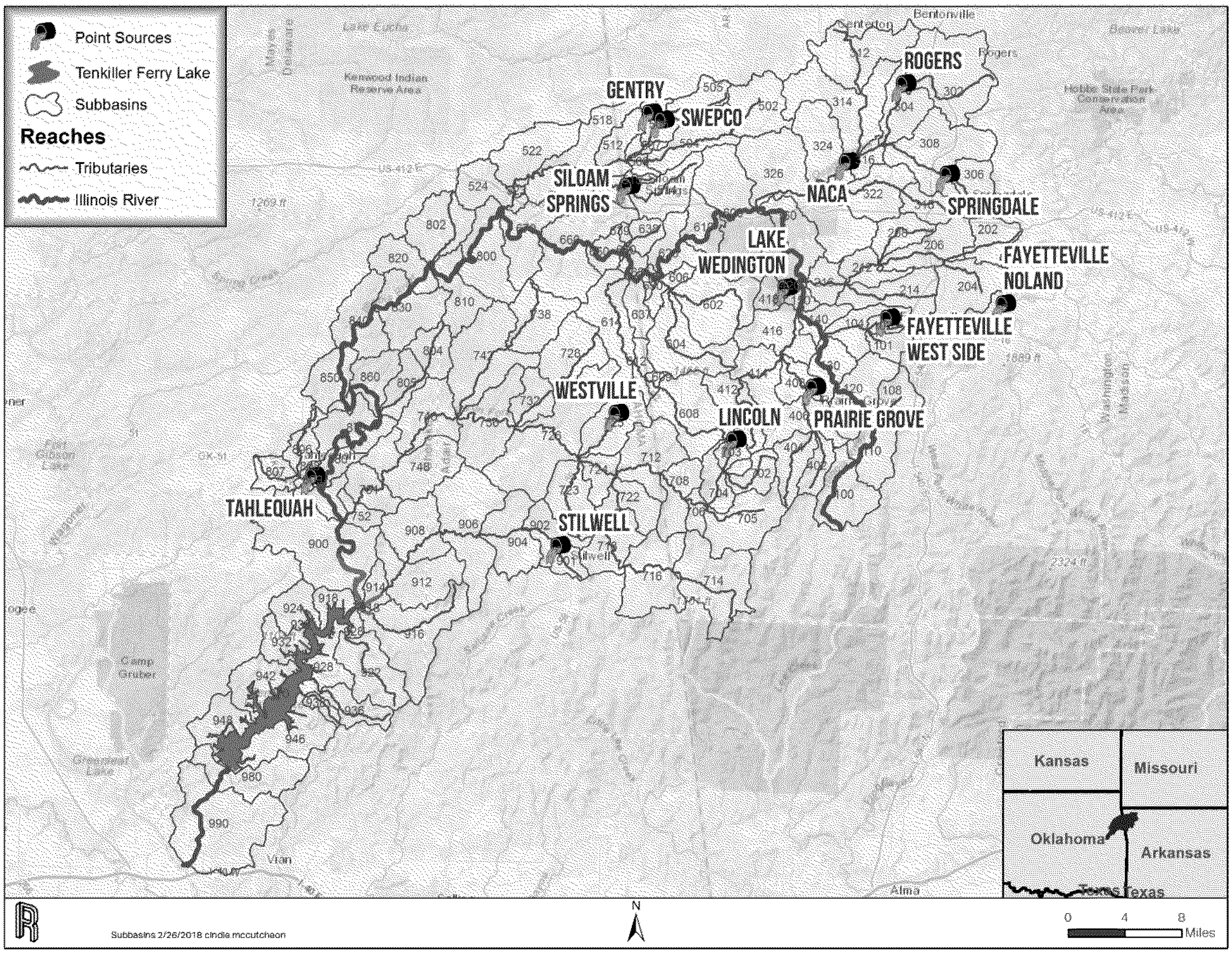


Figure 5.1 Locations of IRW Point Source Dischargers

Add information for the above – RESPEC - DONE

5.2. Load Allocation (LA)

Nonpoint Sources

General description of nonpoint source – RESPEC.

Add subwatershed level load.

5.3. Consideration of Critical Condition

EPA regulations, 40 CFR 130.7 (c)(1), require Loading Reduction to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the impaired streams is protected during times when it is most vulnerable. Critical conditions are important because they describe the combination of factors that cause an exceedance of water quality criteria. They will help in identifying the actions that may have to be undertaken to meet water quality standards.

Insert a paragraph about watershed modeling – RESPEC -- DONE

To a great extent, watershed modeling eliminates the need to pre-define critical conditions for water quality standards violations as it includes and represents the dynamic impacts of both point and nonpoint sources, in conjunction with climatic and watershed characteristics that determine and control the water quality behavior of the watershed. Analysis of the timeseries of the predicted water quality concentrations of the model (daily or hourly) will show when and where in the watershed the water quality standard violations occur. Although low-flow conditions during late summer and fall are often the critical condition of concern for point-source dominated watersheds, this is not always the case in complex watersheds, like the IRW, where both point and nonpoint sources are present. Furthermore, the water quality timeseries can be analyzed to identify the frequency and duration of water quality violations at any point in the watershed, demonstrating the analytical power of the watershed modeling approach.

Insert a paragraph about Lake Modeling -DS

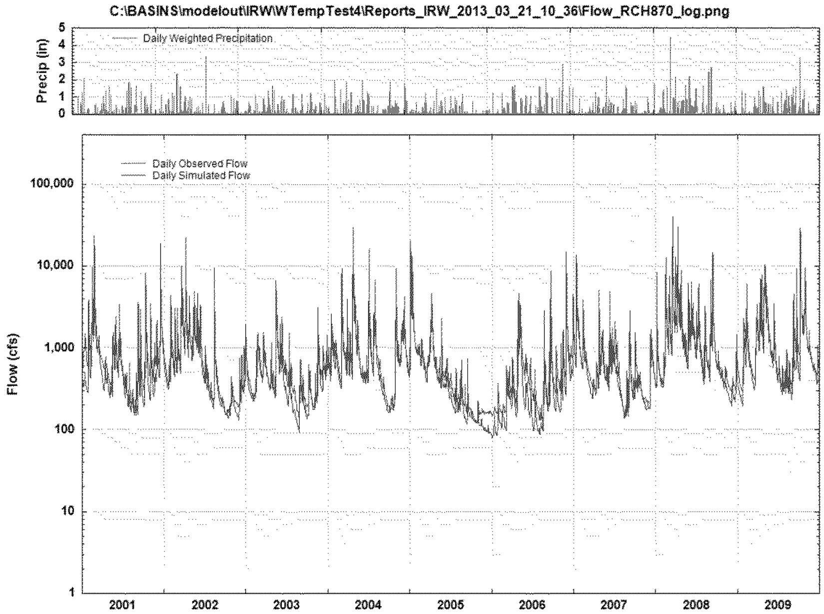
The model simulation period was selected to include both low flow and high flow conditions, thus covering all of the flow regimes. The long-term simulation of 18 years, 1992 to 2009, used in this Loading Reduction modeling study will guarantee that all critical conditions were addressed in the Loading Reduction.

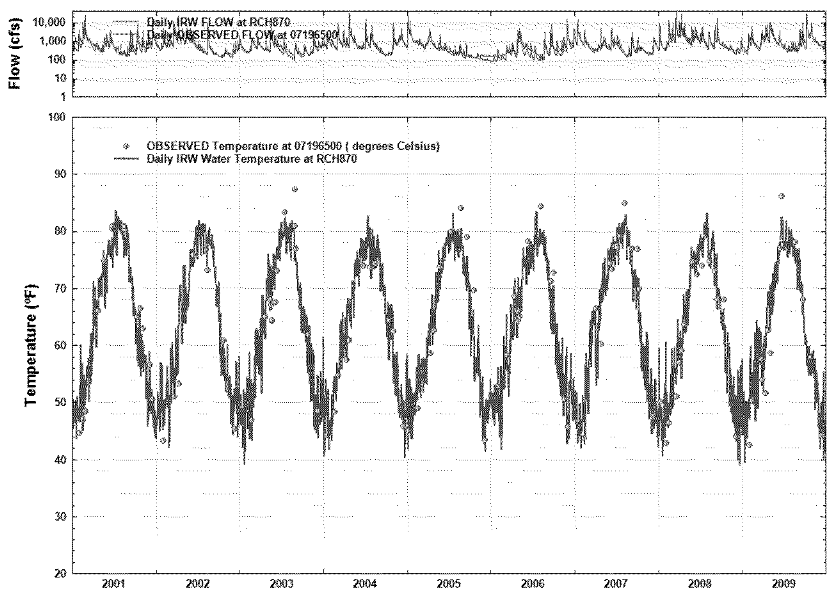
5.4. Seasonal Variability

Describe seasonal variability

Watershed – RESPEC -- DONE

Seasonal variability is inherent in all midwestern watersheds like the IRW. With four distinct seasons during the year, data from the watersheds clearly shows the cyclical nature of the various vegetation and watershed behavior as shown by the flows, temperature and other environmental variables. Figure 5.x shows both the flow variation at the Tahlequah flow gage, and the water temperature variation with the obvious sinusoidal pattern indicative of the seasonal variation in these variables. The air temperature directly affects the water temperature, which in turn has a direct and significant influence on all aquatic processes. The IRW model does a good job of representing the seasonal pattern of flow and water temperature (as shown in Figure 5.x) and the other water quality variables included in the model.





Combine into a single figure. ... Figure 5.x Example Seasonal Variability in the IR

Lake - DS

5.5. Margin of Safety (MOS)

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality.

According to EPA guidance (USEPA, 1991), the MOS can be incorporated into the TMDL using one of two methods:

- Implicitly incorporating the MOS using conservative model assumptions to develop allocations.
- Explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations.

The MOS was implicitly incorporated into this Loading Allocation.

Watershed level – assumptions that help scenic river meets the criteria- RESPEC -- DONE

The IRW model does have an implicit, unquantifiable MOS largely because it has a tendency to somewhat (or slightly) over-predict PO4 and TP concentrations at most calibration sites (based on the published plots). Therefore, any Baseline condition would have somewhat higher TP loads than might be expected. As a result, any needed reduction to meet a TMDL would tend to be higher than really warranted leading to 'better' water quality, i.e., lower final TP concentrations and loads, than would be required if the model was more 'exact' in its TP predictions.

Taim/Sabu – Need to add to this

Lake level – WQ - DS

5.6. Loading Allocation Calculations

The procedures for calculating the TMDL were as follows:

1. The Baseline model was run for an 18-year period from 1992 to 2009, to identify the 30-day geomean TP concentrations that needed to be reduced to meet the 0.037 mg/l TP OK Scenic Rivers water quality standard.

2. Subsequently, numerous model scenarios were executed with global (i.e. state-wide) reductions applied to both point and nonpoint sources in order to identify the general level of reduction needed to meet the 0.037 mg/l TP standard as the 30-day geomean concentration. The scenarios were checked to determine whether or not the standard was met at both the AR/OK stateline (reach 630) and numerous mainstem sites on the Illinois River down to the final stream reach (Reach 890) into Tenkiller Ferry Lake.

3. From Step 2, the scenario with a 69% reduction in all sources for AR, and a 93% reduction for OK, produced compliance with the 0.037 mg/l TP standard at all sites leading into Tenkiller Ferry Lake. The daily loads calculated for this scenario at Reach 630 were 33.9 lb/day TP, and at Reach 870, the daily load was 3,303 lb/day TP. It should be noted that the compliance time period (period when the standard is just met) occurred during the 2005-06 dry period (i.e., December 2005) for the Stateline site, whereas the corresponding time period for the downstream site (Reach 870) occurred in May 1999 during moderate-to-high spring flows.

4. Mean annual loads were then generated for the 69% AR and 93% OK reduction scenario, and the 18-year mean annual load was divided by 365.25 to determine the average daily load at all sites of interest. This produced a TMDL of 291.5 lb/day TP at Reach 630 and 378 lb/day TP at Reach 870. These values are shown in Table 5.x along with TMDL values for other reaches.

5. These daily values were then distributed into the TMDL components as follows:

    a. The annual load allocation provided the WLA component.

    b. The LA was determined by difference, i.e., LA = TMDL – WLA – FG, where FG was estimated as 0.1% of the TMDL.

6. The same calculations were performed at each of the terminal pour points for the impaired waterbodies in OK, as defined on the 2012 303d list.

5.6.1 Load Reduction Scenarios

Add info about the scenario considered and the final scenario – RESPEC

NEED TO ADD THE ADDITIONAL SITES FOR BARON FORK AND FLINT CREEK

Table 5.x TMDLs for Selected Reaches within the IRW

Pour Point	TMDL	WLA	LA	FG	MOS
RCHRES 630 - Illinois River	291.5	18.8	272.4	0.3	Implicit
RCHRES 650 - Illinois River	318.1	18.7	299.0	0.3	Implicit
RCHRES 800 - Illinois River	370.5	22.2	347.9	0.4	Implicit
RCHRES 870 - Illinois River	377.9	22.1	355.4	0.4	Implicit
RCHRES 890 - Illinois River	382.0	22.7	358.9	0.4	Implicit

Add information of the Lake Scenario meeting the Lake WQ – DS

Reference Section 6 for the phased implementation.

5.6.2 Loading Calculations

Add info– RESPEC – Discussed above

5.6.3 Load Reduction Implementations

Add info– RESPEC

5.6.4 Section 404 Permits

Add info– DS -remove this if needed

Stick with TMDL

SECTION 6. TMDL IMPLEMENTAION AND MONITORING RECOMMENDATIONS

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. The second step is to develop a TMDL Implementation Plan. The final step is to implement the TMDL Implementation Plan and to monitor stream water quality to determine if water quality standards are being attained.

In accordance with Section 106 of the Federal Clean Water Act and under its own authority, ADEQ has established a comprehensive program for monitoring the quality of the State's surface waters. ADEQ collects surface water samples at various locations, utilizing appropriate sampling methods and procedures for ensuring the quality of the data collected. The objectives of the surface water monitoring program are to determine the quality of the state's surface waters, to develop a long-term data base for long term trend analysis, and to monitor the effectiveness of pollution controls. The data obtained through the surface water monitoring program is used to develop the state's biennial 305(b) report (Water Quality Inventory) and the 303(d) list of impaired waters.

ODEQ will collaborate with a host of other state agencies and local governments working within the boundaries of state and local regulations to target available funding and technical assistance to support implementation of pollution controls and management measures. Various water quality management programs and funding sources will be utilized so that the pollutant reductions as required by these TMDLs can be achieved and water quality can be restored to maintain designated uses. ODEQ's Continuing Planning Process (CPP), required by the CWA §303(e)(3) and 40 CFR 130.5, summarizes Oklahoma's commitments and programs aimed at restoring and protecting water quality throughout the State (DEQ 2012). The CPP can be viewed at ODEQ's website at the following web address: http://www.deq.state.ok.us/wqdnew/305b_303d/Final%20CPP.pdf. Table 5-3 provides a partial list of the State partner agencies DEQ will collaborate with to address point and nonpoint source reduction goals established by TMDLs.

Point source reductions for this TMDL will be implemented through the NPDES program, which is administered by ADEQ in Arkansas and by ODEQ in Oklahoma.

6.1. Phased Implementation Approach

6.1.1 Phase 1

This corresponds to 72% reduction of all phosphorous sources.

6.1.2 Phase 2

This corresponds to 72% reduction for sources in AR and 90% for sources in OK.

6.1.3 Phase 3

This corresponds to 72% reduction for sources in AR and 99% for sources in OK.

6.1.4 Phase 4

This corresponds to 83% reduction for sources in AR and 99% for sources in OK.

6.2. Post Implementation Monitoring

Observe whether we are meeting the target without going to the next phase.

6.3. Phosphorous Trading

AR do in terms of regulations – put EPA guidance.

6.4. Reasonable Assurances

SECTION 7. PUBLIC PARTICIPATION

Public participation is a necessary step in the TMDL development process. Each state must provide for public participation consistent with its own continuing planning process and public participation requirements. When EPA establishes a TMDL, EPA regulations require EPA to publish a notice seeking public comment pursuant to 40 C.F.R. §130.7(d)(2). EPA believes there should be full and meaningful public participation in the TMDL development process. This section describes the public participation for this TMDL development process.

This section of the document will be updated prior to finalization to reflect the public participation during the public comment period.

SECTION 8. REFERENCES

APPENDIX A. HSPF WATERSHED MODEL

MODEL AS REFERENCED BY INCLUDES THE CHANGES RECOMMENDED BY TECHNICAL WORK GROUP

APPENDIX B. EFDC HYDRODYNAMIC AND WATER QUALITY MODEL

APPENDIX C. STATE OF OKLAHOMA ANTI-DEGRADATION POLICY

Add AR

APPENDIX D. AMBIENT MONITORING DATA: WATERSHED STATIONS AND LAKE STATIONS

APPENDIX E. STORMWATER PERMITTING REQUIREMENTS AND PRESUMPTIVE BEST MANAGEMENT PRACTICES (BMP) APPROACH – WE MAY DROP THIS

APPENDIX F. SANITARY SEWER OVERFLOW (SSO) BYPASS EVENTS – MAY BE REMOVED

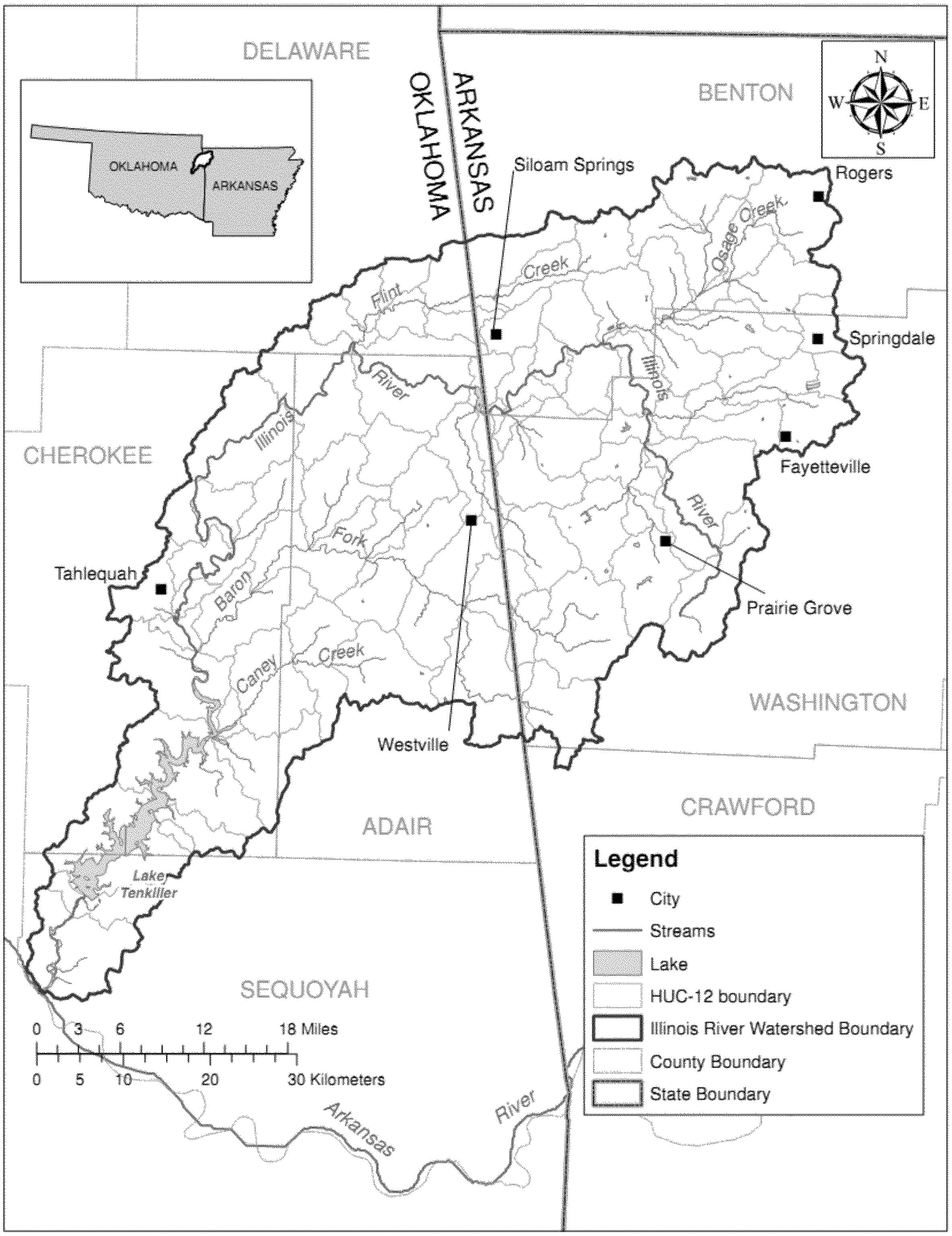

DELAWARE
BENTON
OKLAHOMA
ARKANSAS
N
W
E
S
OKLAHOMA
ARKANSAS
Siloam Springs
Rogers
Osage Creek
Flint
Creek
Springdale
Illinois
River
Illinois
CHEROKEE
Fayetteville
River
Fork
Baron
Tahlequah
Prairie Grove
Caney
Creek
WASHINGTON
Westville
CRAWFORD
ADAIR
Lake
Tenkiller
Legend
City
Streams
Lake
HUC-12 boundary
Illinois River Watershed Boundary
County Boundary
State Boundary
SEQUOYAH
0 3 6 12 18 Miles
0 5 10 20 30 Kilometers
Arkansas
River

Figure 8-1. Sample Figure

Table Error! No text of specified style in document.**-1. Sample Table**

BC	Boundary Group ID	NAME	Data	Cells
1	Dam Release	Dam release	Outflow	3
2	Subbasin 946	Unknown	HSPF NPS catchment	2
3	Subbasin 948	Unknown	HSPF NPS catchment	2
4	Subbasin 942	Unknown	HSPF NPS catchment	2
5	Subbasin 938	Chicken Creek	HSPF tributary	1
6	Subbasin 936	Unknown	HSPF tributary	1
7	Subbasin 928	Unknown	HSPF NPS catchment	2
8	Subbasin 922	Unknown	HSPF tributary	1
9	Subbasin 916	Dry Creek	HSPF tributary	1
10	Subbasin 932	Unknown	HSPF NPS catchment	1
11	Subbasin 924	Unknown	HSPF NPS catchment	1
12	Subbasin 918	Unknown	HSPF NPS catchment	1
13	Subbasin 912	Unknown	HSPF tributary	1
14	Subbasin 914	Caney Creek	HSPF NPS catchment	1
15	Subbasin 752	Baron Fork	HSPF tributary	1
16	Subbasin 890	Unknown	HSPF tributary	1
17	Subbasin 900	Illinois River	HSPF NPS catchment	2
18	Balance Flow		Estimated	4